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EXPLORING THE galaxy-black hole CONNECTION

Every big galaxy has a black hole at its heart. Yet astronomers are just learning how they work together. p. 28

NEW IMAGES!
Hubble uncovers galaxies near the dawn of time p. 56

How rare is life in the universe? p. 34

Giant black holes lurk at the centers of galaxies like the barred spiral NGC 1672. Astronomers are unraveling the mystery behind the galaxy-black hole connection.

AND MORE!

Bob Berman on the magnetic cosmos p. 16

10 top summer binocular treats p. 70

Fun observing the Sun p. 72

Vixen's new refractor outperforms its specs p. 74

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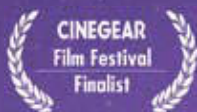
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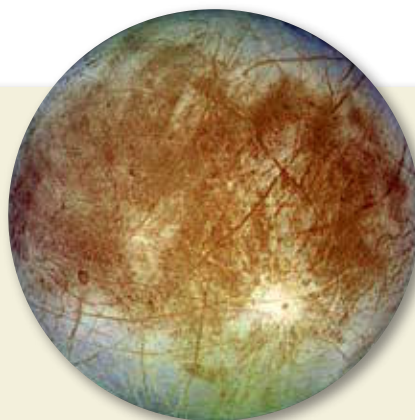
ON THE COVER
The graceful spiral arms of NGC 1672 mask a supermassive black hole that lies at this galaxy's center. All large galaxies seem to have such monsters in their cores.

FEATURES



28 **COVER STORY**
Exploring the galaxy-black hole connection 🎧

Every large galaxy seems to have a supermassive black hole at its heart. Yet no one knows exactly how they feed off each other. **STEVE NADIS**



34 **The new search for life in the universe** 🎧

Astrobiologist Christopher Chyba tells the inside story of how astronomers are searching for other life. **CHRISTOPHER CHYBA**

40 **The Sky this Month**
Spend an evening with Venus.
MARTIN RATCLIFFE AND ALISTER LING

56 **Galaxies near the dawn of time** 🎧
The Hubble Space Telescope's latest and greatest deep-field image uncovers a population of compact and ultra-blue galaxies more than 13 billion light-years from Earth. **RICHARD TALCOTT**

62 **Ask Astro** 🎧
Creating heavy elements.

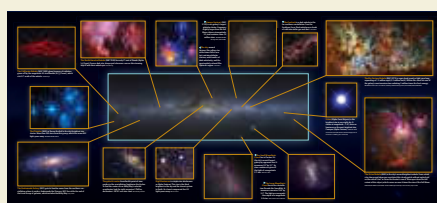
64 **Target 30 obscure celestial gems** 🎧
This list of faint, fainter, and faintest deep-sky targets will take your observing skills to the next level. **MICHAEL E. BAKICH**

70 **10 top summer binocular treats** 🎧
You won't need a large telescope to spot these celestial wonders. **PHIL HARRINGTON**

72 **Fun observing the Sun** 🎧
Double your observing time by targeting our daytime star. **MICHAEL E. BAKICH**

74 **Vixen's new refractor outperforms its specs**
The AX103S offers fine craftsmanship and superb optics. **GLENN CHAPLE**

BONUS POSTER FOLDOUT!



Axel Mellinger's Milky Way mosaic

An amateur astronomer captures our galaxy in glorious detail. **MICHAEL E. BAKICH**

COLUMNS

- 16 **Strange Universe**
Field of dreams.
BOB BERMAN
- 18 **Observing Basics**
The solar system in a nutshell.
GLENN CHAPLE
- 20 **Secret Sky**
Strange meteors.
STEPHEN JAMES O'MEARA
- 76 **Evening Stars**
A special star party in upstate New York.
DAVID H. LEVY

IN EVERY ISSUE

- 8 **This Month in Astronomy**
Farewell to Dick McNally.
- 10 **Beautiful Universe**
- 12 **Astro Confidential** 🎧
Abby Allwood, Todd Henry, Chris Impey, Angela Olinto, Alicia Soderberg
- 14 **Letters**
- 15 **Web Talk**
- 22 **Astro News**
Alien worlds colliding. Kepler mission spies its first planets. WISE mission on a roll.
- 78 **Telescope Insider**
- 79 **New Products**
- 80 **The Cosmic Grid**
- 81 **Advertiser Index**
- 85 **Deep-sky Showcase**
- 86 **Reader Gallery**

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This Month in Astronomy



Farewell to Dick McNally

by David J. Eicher

Sixty-five people have worked on *Astronomy's* editorial staff since the magazine's creation in August 1973. Not all at once, of course — for example, we now have a staff of nine editors. Few have left as large a mark on the magazine and how it works as Dick McNally, who is retiring after serving as a corporate editor-at-large and as the magazine's managing editor and then executive editor for the past 5 years.

Dick didn't come to *Astronomy* as an astronomy enthusiast, but as a professional journalist of very high caliber. He worked at Kalmbach Publishing Co., *Astronomy's* publisher, for 12 years, and has managed publication staffs in seven locations worldwide over a career in journalism that lasted 32 years.

The executive editor received his bachelor's degree in journalism from the University of North Dakota in 1970, along with a commission as second lieutenant in the U.S. Air Force. In the early 1970s, he served as a helicopter pilot in Thailand and in the United States, and he has been credited by the Aerospace Rescue and Recovery Service with three lifesaving missions.

After leaving the Air Force in 1975, Dick flew as a commercial pilot, some of that time as a crop-duster, and started and operated his own helicopter service in Arkansas. In 1977, he accepted a position as a reporter/photographer for two North Dakota weeklies during the off-season for flying, and he ended up staying in that career for a lifetime. He was promoted to editor and managed the newspapers for an absentee publisher.

Dick continued his publishing career as an Air Force public affairs officer in 1979, managing publications in three stateside locations as well as in Germany and Saudi Arabia. During that time, he

served as the director of public affairs for Joint Task Force Southwest Asia (coalition forces deployed to the Persian Gulf region for Operation Southern Watch), and as the managing editor of *Airman*, the official magazine of the U.S. Air Force. He was also assigned as the director of public affairs for the largest technical training base in the Air Force.

Dick has received regional and national awards for his writing, including first place from the National Association of Government Communicators for his feature article "Heroes of the Heart" published in *Airman* magazine. The publications he supervised also received awards, including one that was named Best in the Air Force in its category.

Since retiring from the Air Force as a lieutenant colonel in 1994, Dick has managed magazine staffs at Kalmbach Publishing as well as at the American Legion in Indianapolis. His outside interests include aviation, photography, and water sports. He and his wife of 38 years, Mary Lee, have three grown sons.

All of us at *Astronomy* will miss Dick. His professionalism, attention to detail, and absorbing personality will be missed greatly in the office — and I will miss endlessly reliving the battles of World War II in our discussions in the hallway. We all congratulate him on his retirement and thank him for his extraordinary efforts with *Astronomy*, efforts that helped continue the magazine's tradition as the finest of its kind in the world.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 38, Number 5

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Astro-Tech AT6RC



A tip of the hat

One of the spring sky's finest objects is the magnificent Sombrero Galaxy (M104) in Virgo. This giant spiral lies roughly 35 million light-years from Earth, on the edge of the great Virgo cluster of galaxies. The Sombrero looks like a traditional Mexican hat because we view its dusty disk from just 6° north of the galaxy's equator. Hidden by the light of some 800 billion suns, the galaxy's nucleus harbors a supermassive black hole that weighs a billion solar masses. Approximately 2,000 globular star clusters orbit M104's vast central bulge — 10 times more than the Milky Way's total. 🌌 NASA/ESA/Hubble Heritage Team (STScI/AURA)

by Karri Ferron

OUR TURN

Chris Impey

Professor and Deputy Head of the Astronomy Department at the University of Arizona

What is the most innovative research going on in your field?

Astronomers are using a variety of tools to address the knottiest issues in cosmology: the natures of dark matter and dark energy. Physicists may beat us to the punch with experiments down in deep mines, but astronomers are identifying galaxies and clusters that can work as dark matter “labs” in space. Dark energy is a ubiquitous but elusive component of the universe, where clever redshift surveys and new microwave background observations are likely to give us new insights. It’s a bit of an embarrassment not to understand 95 percent of the universe!

What are some of the coolest things you’ve done in your career so far?

In research, I’ve had a dozen projects with the

Hubble Space Telescope (HST), and the data are simply gorgeous. I’ve also been lucky enough to use most of the world’s largest ground-based telescopes. For me, nothing beats the awesome dark skies and fantastic scenery you get at the Chilean observatories.

In teaching, it’s a toss-up between doing hands-on activities with third graders, whose excitement and curiosity are infectious, and several trips teaching cosmology to Tibetan monks, whose dedication and ability to ask simple but profound questions is inspiring. I enjoy all forms of teaching.

What are your goals for the future?

I’m moving into popular writing, with one book, *The Living Cosmos*, published in 2007, and another, *How It Ends*, out this April. Book-length writing is a craft I want to keep working at; my goal is to seamlessly merge storytelling with astronomy information. In research, I’m hoping to use a large HST survey to tell the story of the coevolution of galaxies and their supermassive black holes.

Chris Impey (center) has made several trips to teach cosmology to Tibetan monks.



Courtesy Chris Impey

Astroideas

What are the current big ideas in planetary habitability?

One question is if Mars ever had the necessary conditions for life, and if evidence of past life is preserved there. The more people study Mars, the more it seems like a place where life could have gained a foothold. There is evidence that water — the prime requirement for life as we know it — once flowed across the surface.

Now the focus is shifting from “follow the water” to gaining a more detailed understanding of habitability and the potential for preservation

of biosignatures. The next big thing for 2018 and beyond will be a focus on seeking signs of life and a push toward sample return.

To understand what kind of biosignatures a primitive martian ecosystem might have left, and how to detect and interpret them, my colleagues and I study Earth’s earliest biosignatures. Early life on Earth was microbial; it’s likely that if Mars had a biosphere for a brief period, it wouldn’t have evolved beyond microbial. The challenges of identifying the earliest microbial fossils on Earth hints at what’s to come if we find signs of microbial life on Mars.

To interpret such a discovery would require wide-ranging observa-

tions on Mars and extensive analyses of returned samples. A possible 2018 mission called MAX-C is envisioned as the first part of a sample return campaign to search for evidence of past life or prebiotic chemistry. MAX-C would make *in situ* observations in support of that objective, as well as collect and cache samples for potential future return to Earth by a subsequent mission.

The more people study Mars, the more it seems like a place where life could have gained a foothold.



Abby Allwood

Field geologist/astrobiologist at NASA’s Jet Propulsion Laboratory in Pasadena, California

Allwood: Ian Burch; Mars: NASA/J. Bell (Cornell U./J.M. Wolff (SSI)



Courtesy Angela Olinto

Angela Olinto

Professor in the Department of Astronomy and Astrophysics at the University of Chicago

8 A.M. Check e-mail and news during breakfast.

8:45 A.M. Drive to the University of Chicago.

9 A.M. Although I like to prepare my class, "The Origin and Evolution of the Universe," the day before, I usually make small changes to the lecture during the hour or so before teaching my class.

10:30 A.M. Teach "The Origin and Evolution of the Universe," a cosmology course for undergraduates of any major. It is a great class when I get strong questions and good participation from my students.

12:30 P.M. Lunch with postdoctoral and graduate students in my group to help us catch up on everyone's work. We usually eat at one of the lunch places next to the department and spend some time going over the latest news on theoretical work or data from the Pierre Auger Observatory, the largest cosmic-ray observatory, located in Argentina.

2 P.M. Catch up on e-mail and other urgent matters; write reports, grant proposals, and letters of recommendation. Try to fight down my constantly increasing "to do" list.

3:30 P.M. Attend department colloquium.

5 P.M. The best part of the day, when there is time to go back to research without distractions. Trying to finish a paper on neutrino fluxes to get it out as soon as possible.

Astroinfluences

How did you become interested in astrophysics?

I grew up on Cape Cod in Massachusetts, home to a large scientific community in the village of Woods Hole. As a young student, I joined this community through a study of the water pollution affecting local ponds. I entered Bates College in Maine, driven to succeed as a chemistry major, but quickly diverted from this path upon taking Astronomy 101. By the end of the first term, I was a double major in physics and mathematics with the goal of becoming an astrophysicist.

During college, I spent summers interning at astronomy departments and research facilities. For my first summer project, I studied catastrophic stellar explosions — supernovae — at Harvard, while my senior project focused on a mysterious class of objects known as gamma-ray bursts (GRBs) at Los Alamos National Laboratory. These energetic bursts of

gamma rays had puzzled astronomers for decades and were attributed to everything from alien communications to colliding comets. While these two projects appeared distinct, soon afterward researchers proposed that GRBs are a special type of supernova. I promptly began a Ph.D. thesis studying the connection between supernovae and GRBs at the California Institute of Technology.

Now, a decade later, I have joined the Harvard astronomy faculty and continue to study cosmic explosions. What excites me about this field is the importance of luck: If a star explodes in the sky, and you are at the right place at the right time, with even a small telescope, your observations may unlock the mystery of these explosions.



Courtesy Princeton Media Office

Alicia Soderberg

NASA Hubble Postdoctoral Fellow at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts

Astrofascinations

What fascinates you most about our stellar neighborhood?

Imagine you're out wandering in a meadow and spot a deer, obviously the largest animal in the vicinity. Then, you notice a few small rabbits over by the trees at the edge of the forest. What you don't notice is the booming population of insects by your feet crawling on your shoes

and those about to swarm onto you from above.

Stars are just the same — the small ones dominate the Sun's stellar neighborhood, but only the attentive eye will notice them.

The smallest stars, also known as red dwarfs, comprise roughly three-quarters of all stars, yet none can be seen with the naked eye. Famous stars such as the nearest, Proxima Centauri, and the fastest-moving (with the highest proper motion

across the sky), Barnard's Star, are red dwarfs. These stars not only dominate the population in numbers, but when combined contain more mass than any other single type of star. So, they surreptitiously run the galaxy via their gravitational power.

Our RECONS group, or Research Consortium on Nearby Stars (www.recons.org), is searching for the Sun's stealthy neighbors and keeping a tally of the discoveries. A glance back from this 2010 census year reveals that within 10 parsecs (32.6 light-years), 49 red dwarf systems have been added to the 213 systems known in the year 2000, including the 23rd, 24th, and 27th nearest.

Recent considerations indicate that planets around these ubiquitous red dwarfs may be suitably balmy for life, and given that so many are nearby, they are prime candidates for planet searches from the ground and in space.



Courtesy Todd Henry

Todd Henry

Professor of astronomy at Georgia State University in Atlanta

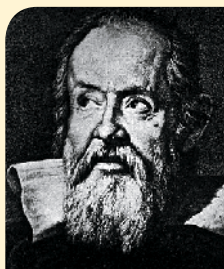
Excommunicated? Excuse me?

I read Glenn Chaple's column in the November 2009 issue, and I must draw your attention to a glaring mistake: The Catholic Church never excommunicated Galileo. It did condemn him and sentence him to imprisonment, which was subsequently "reduced" to house imprisonment. But to write that he was excommunicated is not accurate. Sadly, this myth continues even today.

The Catholic Church takes the censure of excommunication seriously. It is used only after much reflection, prayer, and dialogue. — **Rev. Ronald J. Gripshover, Jr.**, Fredericksburg, Virginia

I apologize for the error. Some "facts" of astronomical history appear so often, we begin to take them as truth, much as we accept without question the concept of Earth being the "third rock from the Sun." A check of my books on astronomical history, backed by an Internet search of reliable sources, confirms your statement that Galileo was not excommunicated.

Interestingly, I called a local parish priest for his understanding of Galileo's status after the Inquisition. He was under the impression that Galileo had been excommunicated. Apparently, this astronomical urban legend is assumed to be true even by some members of the Catholic clergy! — **Glenn Chaple**, Contributing Editor



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Galileo Galilei, despite his house arrest and rocky relationship with the Catholic Church, was never actually excommunicated.

Human exploration needed

I was amazed to read the attitudes against manned space exploration in "Why not robots?" and "No stepping on Mars" in the Letters section of your December 2009 issue.

I do not think for one nanosecond that Lewis and Clark were infected with a "highly charged, testosterone urge" to seek "adventure" when they explored the American wilderness all the way to the Pacific. Their expedition laid the groundwork for the westward expansion of the United States.

The same goes for those of us who want to "go out there." I'm 63. I don't think I'm full of a highly charged, testosterone urge to seek adventure either. Yet, I would leave tomorrow. We want to see what's there with our own eyes, touch it with our own hands, and walk on it with our own feet. We want the human race to expand all the way to the stars, with our own solar system as the steppingstones for our baby steps outbound.

Mankind is undeniably territorial. We need room to expand, and the only place left is outside Earth's gravity well. We need the room on other planets to ensure our survival. Didn't you explore your world as a child? This is no different.

As the saying goes, "The meek shall inherit the Earth. The rest of us are going to the stars!" — **Milton Schick**, Tucson, Arizona

Amazing amateurs

At my older age, I am usually not impressed with magazine reproductions of deep-sky objects photographed by readers using equipment that costs more than my car. They are striking enough, but after seeing Hubble's renditions, amateurs' earthbound photography becomes a "been there, done that" experience. As soon as a photo is tainted with image-altering software, it departs reality and no real science can be done with it.

But two photos published in your December 2009 issue really took my breath away. Foremost was the black-

and-white photo of Mare Humorum on page 71. Never have I seen such a razor-sharp image right down to the pixel footprint. Given the date and time of the photo, I could calculate the height of the mountains and the depths of the craters by measuring the shadows. The crater Gassendi is so richly detailed, it's like I'm in space over the Moon looking down. Being partial to black-and-white photos of solar system objects, I felt like heading for my observatory after reading and trying to produce an image with the quality Paolo Lazzarotti captured.

Likewise, the Jupiter sequence showing Europa's shadow on the cloud tops on page 70 delights me. Once again, the measurable position and size of the shadow on Jupiter's disk allows scientists to calculate Europa's diameter and position.

Bravo. These two photos are what I call astrophotography! Keep them coming! — **John Occhuzzo**, Greensburg, Pennsylvania

Flying to the cross

Stephen James O'Meara's December 2009 column, "The Christmas Cross," provided a fascinating insight into the lore surrounding the constellation Cygnus, or "Northern Cross." The article also brought back fond memories.

I wonder if people know how dependent we World War II U.S. Army Air Forces navigators were on that group's stellar member Deneb? Everyone centered that star in their octant bubble along with other friendly beacons, like Capella and Altair. By "shooting" them from our Plexiglas domes, we could plot triangular fixes on our airborne charts.

I can personally thank Deneb for allowing me, during a domestic training flight as a cadet in 1944, to "split" Nashville, Tennessee, right down the middle! This, despite curtains blinding our plane and a dead radio on what was intended as a purely celestial training mission.

— **Al Weeks, 2nd Lieutenant (ret.)**, Sarasota, Florida

We welcome your comments. Send letters to Astronomy Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.

Observing springtime deep-sky objects with a large telescope

In this video, *Astronomy* magazine Editor David J. Eicher shares 10 of his favorite springtime deep-sky objects, including NGC 4319 and Markarian 205, the NGC 3190 galaxy group, 3C 273, and NGC 3242.



NGC 4319

MULTIMEDIA



Learn more about black holes

Featured video

"Astronomy 101: Black holes"

Astronomy magazine Senior Editor Richard Talcott looks at some of the weirdest objects in the universe: black holes.

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Strange Universe

by Bob Berman

Field of dreams

Magnetism casts a powerful force in our solar system and throughout the universe.

Magnetism. It's forever fascinating. Long regarded as an earthly curiosity, it's now known to play an amazing role across the universe.

In our lifetime, only one type of deep-space object directly affected us: a crushed star smaller than London called a magnetar. One of these threw intense gamma rays at us in 1979; another did it in 2004, causing an aurora. Magnetars get *all* their power from a decaying magnetic field trillions of times greater than Earth's. An astronaut approaching one would have no warning of danger. Yet it would erase his bank cards, plunging his credit score into the 400s. The suddenly broke explorer would then suffer the strangest imaginable death, as all his body's atoms get pulled into icicle shapes.

We actually see magnetism at work through our backyard telescopes. The Crab Nebula's strange glow is synchrotron radiation, caused by electrons changing direction due to the central star's super-magnetism. But we needn't look so far away. Magnetism powerfully affects our own solar system.

Earth's field is, of course, strong enough to move compass needles. We know the historic direction of our magnetic poles because iron in volcanic lava aligns with the field as it solidifies, when it cools below its "Curie temperature" of 1414° Fahrenheit (768° Celsius).

Such basaltic rocks reveal that our planet's field reverses its north-south orientation a few times each million years. Some folks fear the next flip is imminent. But there's no reason it should happen this century, even though Earth's magnetism has weakened mysteriously by 10 percent since 1850. Moreover, magnetic reversals haven't matched the times of

mass extinctions, so they obviously don't hurt us much. A few dazed pigeons might fly around your bedroom.

Magnetism comes from the arrangement of electrons. Normally, we ignore it. We don't even feel it. Yet this force, created by the liquid iron around Earth's solid core, is a good thing. It generates our "magnetosphere," a word coined soon after the Explorer satellite discovered it in 1958. A magnetosphere is protective, filtering out broken pieces of atoms zooming in from the Sun or deep space. Without it, incoming radiation would speed up genetic mutations and evolution. Earth would be different. No

We actually see magnetism at work through our backyard telescopes.

magnetism might mean more squirrels. With a bit more evolution, they might realize zigzagging is a good way to evade hawks but not Camrys.

The only planets in our solar system without magnetospheres are our neighbors Mars and Venus. Mars probably lost it when its core turned solid. Suddenly, the solar wind started coming in, chipping away its atmosphere until it was virtually gone. Radiation now bathes the surface.

That solar wind of high-speed particles comes from the Sun's own magnetism. Its strength matches the one discovered last year on Vega. The Sun's magnetic field spreads across the solar system in a lovely pattern called the Parker spiral, resembling water from a spinning sprinkler.

But it's Jupiter that really grabs our magnetic attention. Jupiter's magnetic story began in 1899 when the genius Nikola Tesla thought he heard radio signals from Mars. Turns out they actually came from Jupiter — the two planets were near each other in Libra. Any rooftop antenna can receive broadcasts from the giant planet on 18 to 23 megahertz. They sound like crashing waves, varying in sync with Jupiter's spin and, weirdly enough, the position of its moon Io. So Jupiter is a pulsar. And not some faint off-shore pirate music station. Its radio emissions blast out 100 gigawatts of power.

We know why. Jupiter's compressed hydrogen core acts like a metal within the planet's fast rotation. This dynamo creates the most powerful magnetosphere in town. It's larger than the Sun. Channeling electrons back and forth between Jupiter's poles, it generates sizzling electricity and constant aurorae. Jupiter's magnetosphere also traps intense radiation and plasma. Their source: Io's volcanoes, which spew a ton of silicon and oxygen into space each second. This material, ionized by the solar wind, becomes the deadly plasma in Jupiter's field. The moons Europa and Ganymede orbit fully within this brutal magnetosphere, too. The radiation pockmarks their surfaces, creating conditions more lethal than standing inside the core of a nuclear reactor wearing a bikini.

Europa's thick ice blocks this extreme radiation. Underneath, its salt-water oceans are safe for life. Green flag conditions. An aquatic paradise that beckons.

Someday, after leaving our protective magnetic bubble, we may learn how to safely penetrate Jupiter's. We won't need a compass to find it. ☛

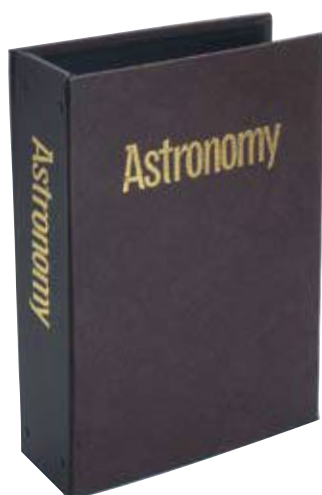


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Observing Basics

by Glenn Chaple

The solar system in a nutshell

Bring the scale and distance of these celestial bodies down to size.

During the course of our telescopic travelings, we routinely visit places like the Moon, the planets, and the Sun, as well as distant stars, nebulae, and galaxies. So vast is the universe that we fail to comprehend the enormity of it all. This month and next, we'll view "the universe in a nutshell," as we scale down the size and distance of some currently visible cosmic sights.

The Moon

The Moon is at its best for evening observations 3 or 4 days before and after First Quarter phase. This month, that window of opportunity occurs between May 17 and 24. The Moon's rugged, cratered surface is an awe-inspiring telescopic sight — a must-see for beginners at public star parties. Because the Moon's disk spans $\frac{1}{2}^\circ$, lunar surface features are visible through even the smallest of backyard telescopes.

Our nearest neighbor in space, the Moon orbits Earth at an average distance of 239,000 miles (384,500 kilometers), or about 30 Earth diameters. Even from a quarter-million miles, sunlight reflected off the Moon's surface reaches our eyes in a mere 1.3 seconds. The Moon's equatorial diameter (2,160 miles [3,475 km]) is approximately one-fourth Earth's.

We can demonstrate a scale of the Earth-Moon system by holding a tennis ball (the Moon) 25 feet from a basketball (Earth). Using this scale, we have shrunk the Earth-Moon system 50 million times, a 1-to-50,000,000 scale.

Saturn

During May, Saturn appears as a 1st-magnitude "star" in Virgo, above and to the right of Spica. With the exception of



Our solar system is so vast that it's sometimes difficult to picture. But by creating smaller scales of our cosmic neighborhood, we can begin to comprehend the relative sizes of Earth, the Sun, and the planets.

the occasional comet, Saturn is regarded as the most wondrous telescope sight in the solar system. Its fabled rings (currently close to edge-on) can be glimpsed with a small telescope and a magnification as low as 30x.

Right now, Saturn is about 840 million miles (1.35 billion km) away. Gazing at Saturn, we see light that left its cloud tops 75 minutes earlier. Second among the planets in size only to Jupiter, Saturn boasts an equatorial diameter of nearly 75,000 miles (120,700 km) — equal to $9\frac{1}{2}$ Earths laid end to end. The rings span 170,000 miles (273,500 km) — nearly three-fourths the distance from Earth to the Moon.

A scale model using a basketball-sized Earth won't work here. Our scaled-down Saturn would be a slightly flattened sphere 8 feet (2.5 meters) across, its readily visible A and B rings spanning 18 feet (5.5m). Let's let Saturn be the basketball. Earth is now a large marble 1.75 miles (2.8 km) away. An accurate representation of the ring thickness is virtually impossible. Cardboard wouldn't work; neither would the finest tissue paper. On this 1-to-475,000,000 scale, the rings would be 0.00008 inch (0.002 millimeter) thick at most — one-twelfth the diameter of a human hair!

The Sun

Our daytime star is a dangerous target for the telescope (even a casual glance without eyepiece projection or the use of an aperture solar filter can cause permanent eye damage). Like the Moon, the Sun sports a $\frac{1}{2}^\circ$ disk, so low power with a small scope will suffice to reveal sunspots.

By solar system standards, the Sun is enormous. Its 865,000-mile diameter (1.4 million km) equals 109 Earths laid side-by-side. The Sun is 93 million miles (150 million km) away — more than 400 times the Earth-Moon distance. In the time it takes for a brisk 1-mile jog (about 8 minutes), light from the Sun reaches Earth.

As was the case with Saturn, the "Earth equals a basketball" scenario isn't practical. On that scale, the Sun would fill an entire basketball court and be situated 2 miles away. Again, we'll let the bigger object (this time, the Sun) be the basketball. Earth is a small-head ($\frac{1}{8}$ inch) map tack placed 90 feet (27m) away. Keeping this scale (1 to 5.5 billion), the entire solar system out to the planet Neptune (a regular-sized marble) would be 1 mile (1.6 km) across.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com. Next month: onward to deep space — "Our galaxy in a nutshell." Clear skies! ☿



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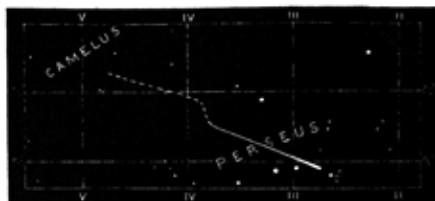
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Strange meteors

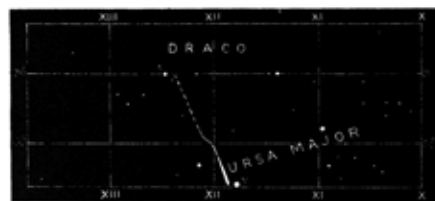
Unusual shooting star trails have perplexed, and fascinated, for hundreds of years.

We expect meteors to move against the stars in straight lines. But these swift streaks of light, poetically referred to as “shooting stars,” don’t always meet our expectations — at least not in the opinion of some skilled observers.

Take, for instance, the experience of Dale Adams of Wichita Falls, Texas. While watching the Orionid meteor shower on the evening of October 21, 2009, he saw what appeared to be a meteor changing direction slightly. Actually, he spotted two Orionids in rapid succession: a bright fireball with a long trail that terminated in a bright flash, and a dimmer one that trailed it nearby in a parallel course. After the leading meteor exploded, the fainter one appeared to change course.



Meteor of 1879, Oct. 20.



Meteor of 1881, June 25.



Meteor of 1885, Sept. 9.

B. J. Hopkins observed three meteors in the late 19th century that displayed zigzagging or wavy paths, as shown here. Hopkins noted that “for the sake of clearness” the bends in the paths are shown greatly exaggerated.

Adams wondered if it was possible for the leading meteor’s explosion to cause a trailing meteor to “skip” like a stone. “It’s always exciting to watch a meteor shower,” Adams said, “but this was something that certainly caught me by surprise!”

Strange? Perhaps. But observations of unusual meteor trails are nothing new. The first well-known sighting occurred December 16, 1742, when Cromwell Mortimer saw a bright meteor from London. At first he mistook it for a “large sky-rocket”; but when it had risen to the height of about 20°, the object moved nearly parallel to the horizon over trees and houses while “waving” in a sinusoidal curve.

This account typifies other early reports. Not until the latter half of the 19th century (during the heyday of meteor observing) did more detailed reports fall into the laps of astronomers.

Illusions?

B. J. Hopkins published the first paper specific to nonlinear meteor trails. In an 1885 *Monthly Notices of the Royal Astronomical Society*, he presented three personal observations of meteors traveling in a “zigzag or wavy path.” Hopkins’ first sighting, on October 20, 1879, characterized the others: “Observed a bright yellow meteor, which described a zigzag path with two bends. ... Appeared between α and β [Camelopardalis], disappeared near θ Persei.”

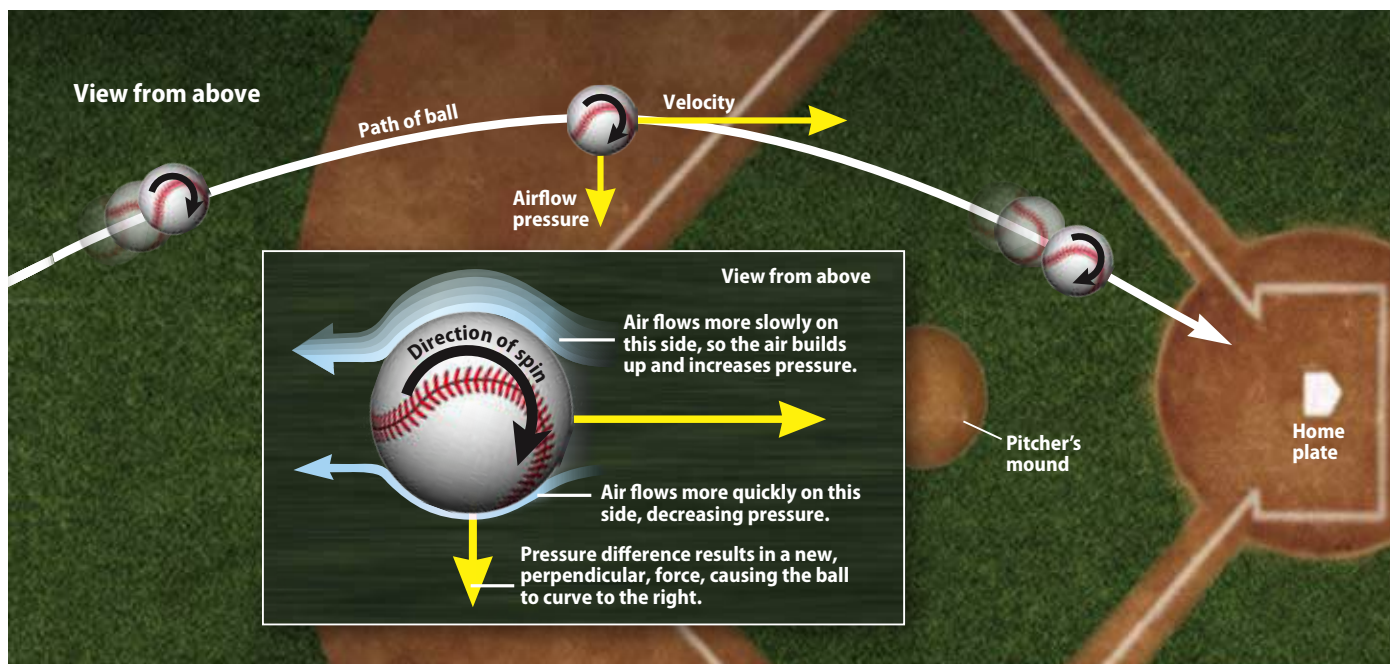
In a correspondence on the subject, William F. Denning told Hopkins that of the more than 1,300 meteors Denning had observed during 1885, only four had nonlinear paths similar to those Hopkins had described. Such rarity inspired Hopkins to describe in an 1886 *MNRAS* yet another curious meteor trail (one similar to what Adams observed in 2009 over Texas).



William F. Denning believed curved meteor trails were physiological illusions. For instance, his drawing here of a “brightish” meteor in Gemini shows it arc up and away from a point between Alpha (α) and Theta (θ) Geminorum. The phosphorescent trail the meteor left behind, however, was a straight line. Thus, Denning deduced, the curvature he saw must have been illusory. Stephen James O'Meara collection

On December 4, 1886, Hopkins spied a brilliant meteor not only with a wavy path but also one “broken in two.” Hopkins saw the meteor curve downward before dividing in such a way that the leading segment did not travel in a line with the trailing portion but in a path parallel to it (about 30' distant). “Whatever caused the meteor to change its course,” Hopkins said, “seems also to have been the cause of the momentary disappearance of the meteor.” He also stressed, “I can most confidently affirm that it was not an illusion.” It wasn’t due to the disappearance of one meteor while a second appeared (“and so as it were continued the path of the first”), nor was it due to the imagination, he said.

Hopkins also recalled a suggestion by his contemporary A. Cowper Ranyard that a meteoroid of irregular shape might cause a meteor trail to curve. But Denning disagreed. In an 1887 *MNRAS*,



Whether on meteors or baseballs, the Magnus effect causes a rotating spherical object to curve off its original, linear path. The rotation causes a difference in air pressure on opposite sides of the object, resulting in a new force pushing on the object. *Astronomy: Roen Kelly*

he countered that the December 4 phenomenon Hopkins witnessed “must have been due ... to the nearly simultaneous appearance of two meteors with parallel paths, and hence, presumably, belonging to the same radiant.” He argued, “As a rule, I believe the alleged crooked paths are nothing more than mere impressions. ... The observer is seldom looking towards the exact place of a meteor’s course, and the glimpse he obtains is more or less hurried, imperfect, and erroneous.”

Denning backed up his rationalization with a personal experience. On December 20, 1886, while watching for “shooting stars,” he suddenly saw a “brightish meteor” that gave him a “very strong impression that the path was much crooked or curled, but about 1½ seconds later a bright streak of phosphorescence came out on the course of the meteor, and I saw it was perfectly straight along its whole length. My idea as to the bent path was therefore quite illusory.”

A different spin?

Despite the growing controversy, observers continued to report meteors with unusual trains. In his 1925 classic book *Meteors*, Charles Olivier noted that out of his first 6,200 meteors, he witnessed 53 moving in abnormal paths. Like Ranyard, Olivier proposed that a nonspherical, rotating meteor entering Earth’s atmosphere “may have its course completely changed after encountering the resistance of air.” Today, there’s a slightly different spin on the matter.

As reported in a 1988 issue of *Earth, Moon, & Planets*, Canadian astronomer Martin Beech of the University of Western Ontario says that on the basis of data culled from historical sources, about one in every 200 visual meteors is likely to show a nonlinear trail, and of such trails, about 60 percent will be continuously curved and 40 percent sinusoidal.

The curved trails, Beech explains, are likely a manifestation of the “Magnus effect”: A spinning spherical object in

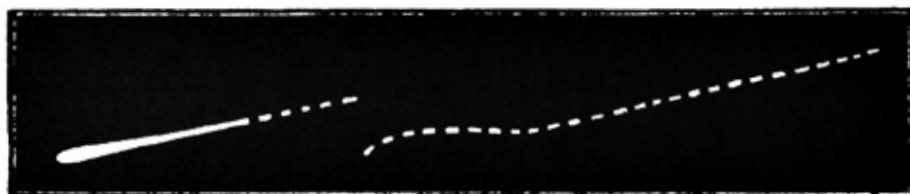
flight causes air to flow differently over one side of the sphere than it does over the opposite side, resulting in a perpendicular force that alters the sphere’s path. If you’ve ever been up against a curve ball, sliced a golf ball, or given a tennis ball a backspin, you’ve encountered the Magnus effect.

Sinusoidal meteor trails, on the other hand, may be the result of nonsymmetrical objects spinning through the air, creating a wobbly or spiral motion (think of a badly thrown American football). But despite Denning’s belief that most curved meteors were illusions, he did pen in a 1923 *MNRAS* article that “meteors nearly stationary are usually slow, often display[ing] a curling or tortuous movement.” This, Beech says, suggests that some stationary meteors may be spiral trails seen head-on.

Into the breach!

Studies of unusual meteor trails remain on the fringe of scientific curiosity. But that doesn’t mean they aren’t worthy of pursuit. The truth, be it the physical forces in nature or a psychological/physiological effect, will be fascinating to learn.

I’m interested in your own observations of curious meteor phenomena. Send me reports at someara@interpac.net. ☛



Another curious meteor train appeared in the sky for Hopkins December 4, 1886. This one was not only curved but also broken into two parallel paths. *Stephen James O’Meara collection*



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Catastrophic collision. To explain HD 131488's unusual distribution of alien dust, astronomers have proposed a collision between large rocky bodies, as shown in this illustration. Lynette Cook for Gemini Observatory/AURA

Alien worlds colliding

Scientists often claim that alien worlds may be fundamentally different from ours, but UCLA astronomers have shown that holds true even for their dust. On January 6, at the meeting of the American Astronomical Society in Washington, D.C., Carl Melis announced the discovery of a far-off star, named HD 131488, with orbiting material of unknown makeup.

"Typically, dust debris around other stars, or our own Sun, is of the olivine, pyroxene, or silica variety, minerals commonly found on Earth," Melis says. "The material orbiting HD 131488 is not one of these dust types. We have yet to identify what species it is — it really appears to be a completely alien type of dust."

Adding to the mystery is the presence of both cold dust orbiting far from HD 131488 and warmer dust orbiting closer. Typically, stars with significant amounts of orbiting warm dust don't also have cold dust in their systems, so Melis and his team proposed a violent theory to account for the anomaly.

"The [warm] dust almost certainly came from a recent catastrophic collision between two large rocky bodies in HD 131488's inner planetary system," Melis says. "The cooler dust, however, is unlikely to have been produced in a catastrophic collision."

His team plans to continue studying the system, and to look for other stars with rocky planet formation. — **BILL ANDREWS**

24 Two surprising
supernovae found

24 WISE mission on a roll

25 A black hole
caught in the act

25 Rocky exoplanet
reveals its secrets

26 Black holes do a waltz

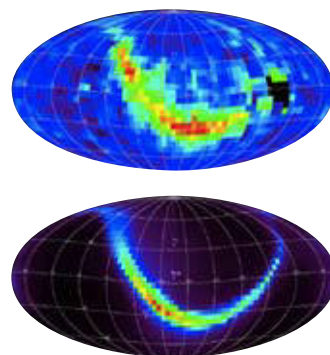
Is the IBEX ribbon a reflection?

In October 2009, astronomers with NASA's Interstellar Boundary Explorer (IBEX) mission announced the discovery of a "ribbon" of bright emissions at the solar system's edge. Now researchers say the ribbon is actually a reflection. Jacob Heerikhuisen, from the University of Alabama in Huntsville, led the study that appeared in the January 10 issue of *The Astrophysical Journal Letters*.

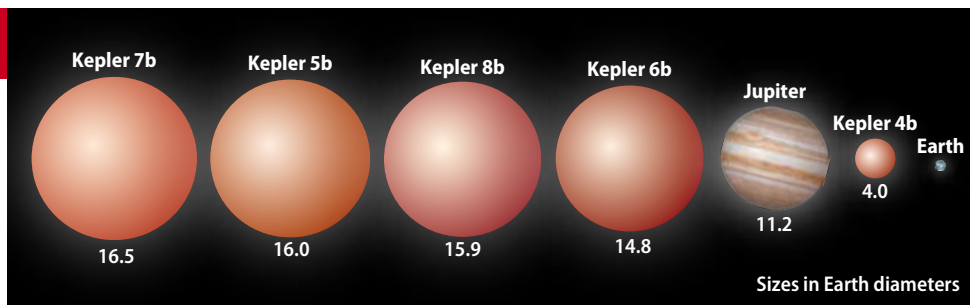
Particles streaming from the Sun — called the solar wind — travel to the solar system's edge.

There, according to Heerikhuisen and his colleagues, the particles interact with powerful galactic magnetic fields. The magnetic fields then fling the particles back in the direction they came from.

If such magnetic fields do produce the IBEX ribbon, Heerikhuisen and his team say, the field's orientation must be closely related to the ribbon's position. Additional IBEX observations combined with 3-D modeling should help astronomers determine if galactic magnetic fields are the cause. — **LIZ KRUESI**



Mirror, mirror. Astronomers say the ribbon seen in IBEX data (top) is actually a reflection off a powerful magnetic field. A simulation of the reflection is shown on the bottom. NASA/IBEX/Heerikhuisen et al. Haubois/Perrin (LESIA, Observatoire de Paris)



Hot worlds. The Kepler spacecraft has discovered five planets, four of which are bigger than Jupiter and one about Neptune's size. All orbit near their host stars and are hotter than molten lava. *Astronomy: Roen Kelly, after NASA*

Kepler mission spies its first planets

In its first 6 weeks of science observations, NASA's Kepler spacecraft has discovered five new planets orbiting stars beyond the Sun. The planets orbit their host stars in periods ranging from 3.2 to 4.9 days. All are significantly bigger than Earth and have surface temperatures above 2200° Fahrenheit (1200° Celsius) — hotter than molten lava. And all circle stars larger and hotter than the Sun.

Kepler's principal investigator, William Borucki of NASA's Ames Research Center, announced the exoplanets January 4 at a meeting of the American Astronomical Society in Washington, D.C.

Kepler finds planets by looking for telltale dips in a star's brightness as an orbiting planet transits in front of it. The spacecraft's camera continuously and simultaneously monitors more than 150,000 stars in the Cygnus-Lyra region. Astronomers on

the ground confirmed the new planets and measured their masses by observing changes in the stars' radial velocities.

Astronomers designated the five planets Kepler 4b, 5b, 6b, 7b, and 8b. (Kepler team members previously had discovered three planets from the ground.) Four of the five have diameters larger than Jupiter. Kepler 4b is the smallest, at just about Neptune's size. But the strangest has to be Kepler 7b. It has a density just 17 percent that of water — as light as Styrofoam. Saturn, the least dense planet in our solar system, is 4 times as dense.

Over the next several years, Kepler should discover thousands of planets, many of which will be much smaller than the first five. In all likelihood, dozens should be similar to Earth in size and temperature. — **RICHARD TALCOTT**



Disappearing in a cloud of dust

Dust bunny. A vast region of sand dunes occupies much of the high northern latitudes on Mars. In winter, carbon dioxide freezes out of the planet's thin atmosphere and covers the dunes with a layer of dry ice. In spring, the Sun warms the terrain and the ice sublimates back into the air. Sand dislodged from the dune crests cascades down, creating the dark streaks seen in this photo. Look carefully, and you'll spy a small cloud of dust kicked up by the falling debris (arrow). The Mars Reconnaissance Orbiter snapped this picture during the northern martian spring. Scientists released the image January 6. — **R. T. NASA/JPL/University of Arizona**

A SERIOUS ANTIMATTER

Notre Dame scientists at the January 4 meeting of the American Astronomical Society announced the discovery of a stellar explosion so violent that it created matter/antimatter pairs.

SHAPING DARK MATTER

Dark matter surrounding the Milky Way's disk is shaped like a giant flattened beach ball, according to UCLA astronomers January 6 at the meeting of the American Astronomical Society.

BLACK HOLE BOUNDARY

The galaxy NGC 300 is home to the farthest known stellar-mass black hole ever detected, said European Southern Observatory astronomers January 27.

GOOD NIGHT, MOON

NASA's 2011 budget, unveiled February 1, cancels the Moon-going Constellation Program and instead focuses on basic research and private industry.

CHILLING WITH THE STARS

Astronomers using the United Kingdom Infrared Telescope in Hawaii announced January 29 that they had discovered the coolest brown dwarf known.

ALL RIGHT, ALMA!

The Atacama Large Millimeter/submillimeter Array announced January 2 that it had linked three advanced antennas at its Chile site, passing a milestone that promises better imaging.

HUBBLE HELPER

Astronaut John Grunsfeld, who serviced the Hubble Space Telescope, was named deputy director of the Space Telescope Science Institute on January 4. The institute oversees Hubble.

FERMI'S LATEST FIND

NASA announced January 5 that its Fermi Gamma-ray Space Telescope has helped astronomers discover 17 more millisecond pulsars in the Milky Way.

EXTRA SMALL EXOPLANET

On January 7, at the meeting of the American Astronomical Society, astronomers announced the discovery of the second-smallest exoplanet around a normal star.

IRONIC IMAGES

NASA astronomers imaged the solar corona in the near-infrared emission line of highly ionized iron for the first time, the agency announced January 5.



Boom. A core-collapse supernova produces a powerful explosion of expanding, nearly spherical material. Bill Saxton, NRAO/AUI/NSF

Two surprising supernovae found

Astronomers report they have detected jets of material traveling faster than half the speed of light after analyzing two supernovae — explosions marking the death of massive stars. This is some 20 times faster than theory predicts. Two papers from two different teams — one led by Zsolt Paragi of the Netherlands-based Joint Institute for Very Long Baseline Interferometry and the other directed by Alicia Soderberg of the Harvard-Smithsonian Center for Astrophysics — appeared in *Nature* January 28.

When a massive star runs out of fuel, its core collapses into a neutron star or a black hole. The rest of the material explodes into space as a supernova. Occasionally (less than 1 percent of the time), one of these “core-collapse” supernovae produces an even more powerful blast, called a gamma-ray burst (GRB). Astronomers believe that in GRBs, material falling toward a central black hole is then boosted away at extreme speeds. These speedy jets of particles are telltale signs of GRBs.

However, neither group of astronomers detected gamma rays with the supernovae analyzed in the *Nature* papers, implying that they can't be GRBs. Both teams instead detected the supernovae's radio emissions.

“These observations are the first to show that some supernovae are powered by a central engine,” says Soderberg. “There must be some rare physical property that separates the stars that produce the ‘engine-driven’ blasts from their more-normal cousins.” But they don't yet know what that property is. — L. K.

WISE mission on a roll

NASA's Wide-field Infrared Survey Explorer (WISE) has had a great start. The craft launched December 14 and jettisoned its cover 15 days later. Then on January 6 at a meeting of the American Astronomical Society in Washington, D.C., the WISE team released the telescope's first image. The exposure covers an area about 3 times that of the Full Moon in the Carina constellation.

WISE is a survey telescope set to continuously scan space. It will take about a million images of the entire sky. In the photo released January 6, the scope captured the infrared radiation from some 3,000 stars. Over WISE's 10-month life, it should gather light from millions of objects.

Scientists estimate WISE will find hundreds of previously unseen near-Earth objects and about 100,000 unknown asteroids in the main asteroid belt (which sits between Mars and Jupiter). Researchers expect the mission to spot most of those objects during its all-sky survey, which will



First light. This 8-second exposure showcases three of the Wide-field Infrared Survey Explorer's four infrared bands. The telescope spotted about 3,000 stars in this first image. NASA/JPL-Caltech/UCLA

last some 6 months. Then WISE will re-observe about half the sky over the following 3 months or so — until the spacecraft runs out of coolant for its infrared images.

Asteroids absorb sunlight and radiate heat (in the infrared spectrum). Infrared emission gives a better estimate of an object's size than visible light because visible radiation depends on an object's composition and reflectivity. To detect the small heat signal from an asteroid, WISE must remain under frigid temperatures. Liquid hydrogen cools the spacecraft to just a few degrees above absolute zero.

Only 2 weeks after opening its eye, the scope's software discovered a never-before-seen near-Earth asteroid. Astronomers estimate that the asteroid, designated 2010 AB78, is 0.6 mile (1 kilometer) wide. Follow-up observations helped them determine the object's orbit, which is elliptical and tilted to our solar system's plane. As of now, 2010 AB78's orbit doesn't make it an impact threat to Earth, say scientists.

Shortly after the asteroid discovery, WISE also found its first comet. The object, P/2010 B2 (WISE) is about 1.2 miles (2 km) in diameter and has a 4.7-year elliptical orbit.

The WISE mission began its all-sky survey January 14. Scientists expect to release preliminary images from this survey in spring 2011. Given its first month's news, we should expect a lot from the remaining nine. — L. K.



New view. WISE released an image of the Andromeda Galaxy February 17. Blue shows older stars, and red and yellow show dust heated by young stars. NASA/JPL-Caltech/UCLA



NASA/JPL-Caltech/STScI

Spying on our galactic neighbor

Explore the depths. The Small Magellanic Cloud (SMC), a satellite galaxy near our Milky Way, lies about 200,000 light-years away. This infrared portrait by NASA's Spitzer Space Telescope unveiled January 6 at the meeting of the American Astronomical Society displays the galaxy's main body in more detail than ever. The "bar" on the left displays old stars (shown in blue) and young ones illuminating nearby dust (in green and red), while the "wing" to the right contains mostly young stars. — B. A.

A black hole caught in the act

Astronomers using the Chandra X-ray Observatory have discovered an intermediate-sized black hole ripping a star to shreds. The black hole lies in a globular cluster belonging to NGC 1399, an elliptical galaxy located some 65 million light-years from Earth in Fornax.

Although strong evidence exists for stellar-mass black holes (weighing up to a couple of dozen solar masses) and supermassive black holes (100,000 solar masses or more), the case for intermediate-mass black holes (100 to 10,000 solar masses) is tenuous.

But this new object seems to fit the bill. If such a black hole lies in the dense stellar environment of a globular cluster, its gravity should occasionally tear apart a star. As debris from the disrupted star falls toward the black hole, it forms a hot accretion disk that emits X-rays. Farther away from the black hole, the shredded star's debris absorbs some of those X-rays and re-emits them at optical wavelengths.

Those are precisely the observational signatures that University of Alabama astrono-



X-ray: NASA/CXC/UA/J. Irwin et al.; Optical: NASA/STScI

Star stripped. Observations of a globular star cluster (arrow) in the elliptical galaxy NGC 1399 show that it likely contains a 1,000-solar-mass black hole ripping a white dwarf to shreds.

mer Jimmy Irwin and his colleagues found in the NGC 1399 globular. Just as interesting, the shredded debris shows spectral lines of oxygen and nitrogen but no hydrogen — a sign that the disrupted star was a white dwarf.

Irwin says the material's velocity, measured from spectra taken with the 6.5-meter Magellan telescopes in Chile, show that the black hole weighs 1,000 solar masses. Irwin announced the discovery January 4 at an American Astronomical Society meeting in Washington, D.C. — R. T.



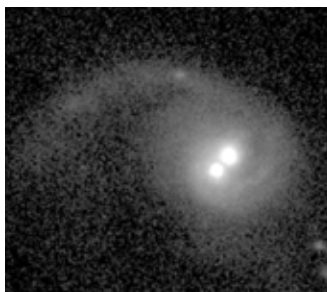
Extreme exoplanet. The most earthlike exoplanet ever discovered, the rocky world CoRoT-7b (illustrated above) is likely a molten landscape of fiery volcanism and may have started out as a gas giant. ESO/L. Calçada

Rocky exoplanet reveals its secrets

The first terrestrial planet found outside the solar system, a distant world named CoRoT-7b, drew more than its share of attention at January's meeting of the American Astronomical Society in Washington, D.C. On January 6, one announcement pegged the exoplanet as a likely molten wasteland, and another suggested it is potentially the remnant of a gas giant. The rocky world is the smallest known exoplanet around a normal star, some 70 percent larger than Earth and 4.8 times as massive.

The first finding, announced by Rory Barnes of the University of Washington, describes CoRoT-7b as a volcanic fire world. "CoRoT-7b could have multiple volcanoes going off continuously and magma flowing all over the surface," says Barnes. He and his colleagues suggest the extreme landscape came about because of the planet's close proximity to its sun, some 60 times closer than Earth is to our Sun.

The second finding, announced by Brian Jackson of NASA's Goddard Space Flight Center in Greenbelt, Maryland, proved even more provocative: This rocky world may have started out as a gas giant of Saturn's size. The tidal pull of CoRoT-7b's nearby star has likely pulled the exoplanet closer over time in a process called tidal migration; as the planet's heat increased, evaporation into space left the planet with less and less mass. "You could say that, one way or the other, this planet is disappearing before our eyes," Jackson says, and it's likely lost many Earth masses of material since first forming. "CoRoT-7b may be the first in a new class of planet: evaporated remnant cores," he adds. — B. A.



Ballroom dance. The two bright spots near the center of this distorted galaxy mark the positions of supermassive black holes and the hot gas surrounding them. NASA/STScI

Black holes do a waltz

Astronomers have found 33 pairs of supermassive black holes within distant merging galaxies. The discovery shows that such dual black holes form far more frequently than previously known and provides a measure of how often galaxies merge. Julia Comerford of the University of California, Berkeley, announced her team's findings January 4 at an American Astronomical Society meeting in Washington, D.C.

Nearly every large galaxy contains a monster black hole. So, whenever two galaxies merge with each other, their black holes perform an intricate dance choreographed by Isaac Newton and his laws of gravity and motion.

Comerford's team found 32 of the waltzing black holes in the DEEP2 Galaxy Redshift Survey and the 33rd on a Hubble image. The researchers identified the dancers by the motions of gas falling into the black holes. Spectra taken with the 10-meter Keck II Telescope on Hawaii's Mauna Kea show that the dual black holes dance at speeds of about 500,000 mph (800,000 km/h) and are from 3,000 to 8,000 light-years from each other.

The galaxies all appear red and lie between 4 and 7 billion light-years from Earth. Based on their research, the team members estimate that red galaxies at these distances underwent three mergers every billion years. — **R. T.**

Seeing Betelgeuse like never before

An international team led by astronomers at Paris Observatory released the most detailed image yet of the red supergiant Betelgeuse January 12. It reveals in detail the surface of the star, about 640 light-years away.

Particularly exciting are two hitherto unsuspected giant bright spots — so giant that, despite covering only a fraction of the surface, their size is similar to the distance between Earth and the Sun. Scientists think these areas are the equivalent

of a local phenomenon: sunspots. This means both stars display the effects of convection, which is the transport of heat by currents of matter.

This is the first time astronomers could clearly see convection taking place on a star other than the Sun. By observing such a familiar process take place on a supergiant, whose physical characteristics remain unexplained, scientists are one step closer to understanding these stellar mysteries. — **B. A.**



Betelgeuse, Betelgeuse, Betelgeuse! This image of Betelgeuse from Paris Observatory reveals two bright spots about as wide as the Earth-Sun distance. They indicate areas where temperatures differ from the average, much like the Sun's spots. Haubois/Perrin (LESIA, Observatoire de Paris)

BRIEFCASE

A star set to explode?

For a star in a binary system to explode as a supernova, it must obtain enough mass to reach a critical threshold. Astronomers from Villanova University announced at the January meeting of the American Astronomical Society that the recurrent nova T Pyxidis system's spectrum matches the simulated spectrum of a star close to the mass limit. — **L. K.**

Asteroid colors change near Earth

As a near-Earth asteroid passes close enough to Earth, tidal forces will induce landslides and other processes that move material around on the asteroid's surface. This reshuffle brings up fresh material, making the asteroid's color match that of most meteorites, say astronomers. Richard Binzel of MIT and colleagues published their asteroid findings in the journal *Nature* January 21. — **L. K.**

Stellar magnet

For the first time, astronomers have directly radio-imaged the magnetic field associated with a star other than the Sun. The team studied the binary system Algol in Perseus and found that a magnetic loop emerges from the poles of the smaller star in the pair. The study, led by William Peterson of the University of Iowa, appeared in the January 14 issue of *Nature*. — **L. K.**

25 years ago in Astronomy

In the May 1985 issue of *Astronomy*, Barry Parker explored the questions behind "Celestial Pinwheels: The Spiral Galaxies."

"Behind the graceful swirl of a galaxy's spiral arm lie two intriguing mysteries," Parker wrote. "What creates these features — and what preserves them?" Touching on all aspects of spiral galaxies, from their defining characteristics through their history up to modern (at the time) models of their formation, Parker never lost his sense of wonder describing "the most beautiful objects in the universe."

In the end, despite recent advances, Parker wrote, "Is there any theory that wraps up all the spiral galaxies in a single package? Unfortunately, there isn't. ... There is still much to be learned and much to be done." And this is still the case.



May 1985



May 2000

10 years ago in Astronomy

In "SETI and the science wars" from the May 2000 issue of *Astronomy*, astrobiologist David Grinspoon came up with an unusual answer to an age-old question. "How much of science is invented and how much is discovered? ... The answer lies in SETI: The Search for Extraterrestrial Intelligence."

Grinspoon argues that comparing our laws of science with an alien culture's represents the best way to quell the science wars "raging" in academia, where scientists argued they looked for objective truth but humanists argued there was no such thing. "It seems possible to me that some kind of science will be the one thing that we have in common with [extraterrestrials]," he wrote, though he allows that they may also enjoy gangsta rap and *The Simpsons*. — **B. A.**



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Exploring the galaxy-black hole connection

Every large galaxy seems to have a supermassive black hole at its heart. Yet no one knows exactly how they feed off each other. **by Steve Nadis**



A high-speed jet of subatomic particles beams from the giant elliptical galaxy M87 in Virgo. The source of this bluish jet is a supermassive black hole in the galaxy's core.

NASA/ESA/Hubble Heritage Team (STScI/AURA)

Understanding family dynamics can be a daunting and sometimes hopeless task. The influences are often subtle, the agendas hidden, and the motives tangled. And history shades events in almost imperceptible ways. What holds true for human families also may apply to families of the cosmic sort, such as the “families” comprising central black holes and their parent galaxies.

Throughout the 1990s, astronomers increasingly became aware of the intimate, though enigmatic, connections that exist between black holes and galaxies. One vital realization is that supermassive



Beautiful barred spiral galaxy
NGC 1672 harbors a supermassive black hole at its center — as do all large galaxies astronomers have studied. The light from billions of stars masks the black hole.

NASA/ESA/Hubble Heritage Team (STScI/AURA)

black holes — those possessing the mass of millions, if not billions, of suns — are not rare accessories that adorn only the most exclusive galaxies. Instead, every large galaxy astronomers have studied in detail has an enormous black hole lurking near its center. This one-to-one correspondence between large galaxies and black holes suggests a fundamental link between these two cosmic entities.

Fit to be tied

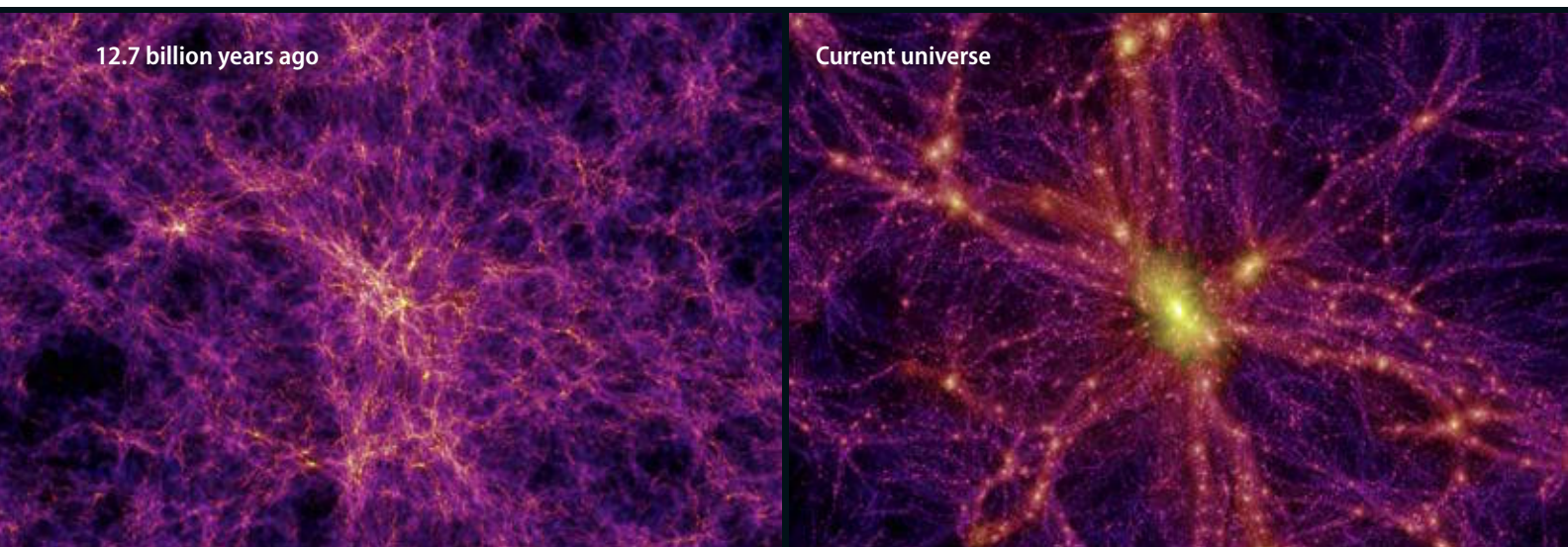
In 1993, University of Texas astronomer John Kormendy uncovered a correlation between the mass of a central black hole and that of its host galaxy. To be more

precise, it was between black holes and elliptical (football-shaped) galaxies and between black holes and the bulges (central concentrations) in spiral galaxies.

Observations have fixed this mass ratio at somewhere between 0.1 and 0.2 percent. Caltech astronomer Dominik Riechers narrows it down further, to about $\frac{1}{700}$ (0.14 percent). “Since we see the same ratio over a range of galaxies of different masses and at different stages of evolution, we assume there must be some mechanism that regulates the growth of the black holes and galaxies, as well as some way of communicating between them,” says Riechers.

By 2000, the fit looked even better, as two teams of astronomers found a correlation between black hole mass and “velocity dispersion” — the random velocities of stars orbiting within the bulge. What makes this correlation particularly striking is that the majority of stars in the bulge lie far enough from the black hole to be totally immune from its gravitational influence, explains Kormendy, a member of the team headed by his Texas colleague Karl Gebhardt.

“If there’s a tight correlation between the black hole mass and some property of the galaxy that doesn’t even know a black hole is there,” says Kormendy, “that really



Computer simulations show the intimate relation between black holes, quasars, and galaxies. A simulation of the universe a billion years after the Big Bang (left) reveals black holes with masses greater than a billion Suns already had formed and were the driving forces behind the first quasars. A snapshot of today's universe from the same simulation (right) shows that those quasars evolved into the most massive galaxies at the centers of the biggest clusters. V. Springel (MPIA) et al.

speaks to the notion of 'coevolution.'" Coevolution implies that the evolution of black holes and galaxies is some sort of tandem process in which the two parties "communicate" through feedback. Since 2000, Kormendy adds, "all sorts of people have tried to come up with theories for how black holes and galaxies talk to each other, and how that talking creates this correlation."

The start of the new millennium brought a dawning sense that scientists can't understand black holes without understanding galaxies. A picture emerged of black holes and their galactic hosts growing together, in "lock step" as it were. All that remained was to explain exactly how this happened.

Not so fast

A decade has passed, and one might think that researchers would have worked out the details of black hole-galaxy interactions. Unfortunately, that is not the case. Although scientists have made progress on the observational front, an overarching theory that weaves together the various threads remains elusive.

"Everyone is fumbling around, trying to see what the next big insight will be," says University of Michigan astronomer

Douglas Richstone. "The correlations that we've observed in the nearby universe probably exist at earlier epochs than we've documented so far, but it's still a deep mystery as to how these correlations developed and when they developed."

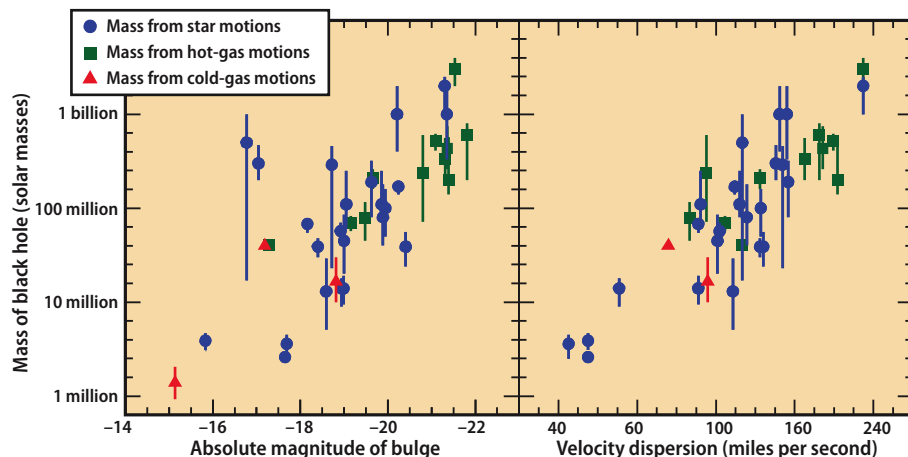
The problem is not that scientists don't have a theory, Richstone adds. "If anything, we have too many theories. If you go to five different doctors and get five different diagnoses, you might get a little suspicious."

Most of what astronomers know today has come from observations rather than theory, says Stanford astrophysicist Tom Abel, a theorist who specializes in com-

puter simulations. They're still far from being able to make firm predictions about how black holes and galaxies interact and evolve, says Abel, "because you have to understand all the things that happen in the middle of galaxies over the course of billions of years in order to have a truly predictive model."

That's a tall order, and it's no surprise that theory has lagged behind observations. Meanwhile, observers are trying to whittle away at existing uncertainties. For instance, they are busy determining the mass correlations with ever-increasing accuracy. That information, in turn, could lead to better theoretical models

Forging the galaxy connection



A central black hole's mass tracks with that of its host galaxy's bulge. Astronomers can estimate the bulge's mass from its luminosity (absolute magnitude, shown at left) or from the random motions of stars in the bulge (velocity dispersion, shown at right). *Astronomy*: Roen Kelly, after John Kormendy

Contributing Editor **Steve Nadis** is co-author of *The Shape of Inner Space*, a book about the mathematics of string theory that Basic Books plans to publish in autumn 2010.

and help solve some of the existing conundrums. So far, the empirical data is painting a more nuanced picture than what astronomers might have drawn a decade ago. In particular, the research has raised key questions about the so-called lock-step scenarios in which black holes and galaxies waltz through cosmic history hand in hand.

Peering into the abyss

In a February 2009 paper, Yale University astronomer Kevin Schawinski and colleagues cast doubt on what arguably had been the leading mechanism advanced to account for black hole-galaxy coevolution. The standard explanation goes something like this: As a black hole gravitationally pulls in surrounding material, the gas circles the abyss faster and faster as it approaches the black hole's event horizon — the point of no return. The material forms an accretion disk around the black hole, and friction within the disk makes it incredibly hot.

The disk becomes a powerful source of X-rays and other radiation as well as a trigger for high-speed jets that spew out matter. At the peak of its feeding frenzy, the black hole gives birth to a quasar, one of the brightest types of objects in the universe and the most luminous kind of active galactic nucleus (AGN). When the black hole accretes matter at a more leisurely pace, this central engine becomes a more pedestrian AGN.

The theory holds that all the energy emitted by the AGN would clear out stray material from the vicinity of the black hole. This would curtail the black hole's own growth while simultaneously heating any nearby gas so it could no longer condense into stars. In this way, the AGN would regulate the growth cycles of both the black hole and the galaxy — they would keep on growing until the AGN spewed out enough energy to shut them both down.

Although this theory still has many adherents, Schawinski and company suggest that the above chronology doesn't quite add up. The researchers used data from the Swift and ROSAT X-ray satellites and the ground-based Sloan Digital Sky Survey to identify 16 nearby galaxies and their accompanying black holes. The black holes showed up clearly because their AGNs were in high gear, sending



Twin jets erupt from the active nucleus of the Seyfert galaxy 3C 219. The bright dot at the galaxy's center is emission from material swirling around the central black hole. NRAO/AUI

out strong bursts of high-energy X-rays. Schawinski's team wanted to find out what the galaxies were up to when the AGNs were most active.

How green is my valley

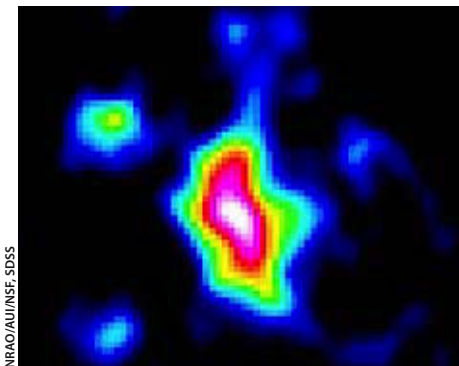
Astronomers long ago recognized that young star-forming galaxies are blue. This occurs because short-lived, massive stars dominate them, and those behemoths burn hot and emit most of their visible light in the blue part of the spectrum. These stars die off within a few million years and are gradually replaced by smaller and cooler ones, which give off more red light.

But the rapidly growing black holes spotted by the Yale-led group inhabit what Schawinski calls "the green valley," galaxies populated mainly with stars of intermediate colors. "The technique we've pioneered here uses stars as a cosmic clock to age-date the sequence of events," he says. "It's like archaeology: You don't know when a particular pot

was made, but you know the layer it's in and the age of the layer. We use the stars themselves as the 'layer' to figure out when lots of star formation occurs."

The approach shows that AGNs reach their most active state in green galaxies, about 100 million years after star formation crested in the earlier, blue period. By this reckoning, AGNs cannot shut down star formation because star formation winds down long before the AGNs turn on. If Schawinski and his collaborators are right, the conventional scenario is off in some critical details. "This whole interplay — this coevolution between black holes and galaxies — may be more complicated than we once thought," he says.

Another 2009 paper seems to corroborate this view. X. Z. Zheng of China's Purple Mountain Observatory, Eric Bell of the University of Michigan, and others examined some 900 galaxies with bulges. Relying on data from infrared, optical, ultraviolet, and X-ray space telescopes, the team concludes that star formation



NRAO/AUI/NSF, SDSS

The distant galaxy J1148+5251, seen as it was less than 1 billion years after the Big Bang, has a central black hole proportionally larger than those in the nearby universe. Radio observations of this and other distant galaxies suggest that galaxies formed after their black holes.



Black holes may be significantly bigger than astronomers thought. For example, researchers found that the central black hole in M60 (the giant elliptical galaxy at center) weighs 4.5 billion suns — twice as massive as earlier studies showed. NRAO/AUI/NSF

and black hole accretion happen at completely different times and that completely different events trigger them.

The findings suggest that if we want to say that black holes and galaxies coevolve, this term must have a broader meaning. “Coevolution in this case occurs in different times and places,” says Bell. “Star formation is substantially out of sync with black hole growth, yet they can still catch up to each other through some other mechanism.” Their study, he admits, doesn’t really shed light on what that mechanism might be.

Recently, researchers even called into question the sanctity of the black hole-galaxy mass correlation, which has held up since 1993 and seemingly improved

with time. Riechers and Chris Carilli of the National Radio Astronomy Observatory are part of an international team examining the black-hole-to-galaxy mass ratio throughout cosmic history. Does the ratio measured in the nearby universe (about 0.14 percent) also apply to the universe’s first galaxies, which formed within a billion years of the Big Bang?

The team used the Very Large Array radio telescope in New Mexico and the Plateau de Bure Interferometer in France to probe deep space. The measurements “are really on the hairy edge, right at the limits of what can be done today,” notes Carilli. Although the astronomers admit their error bars are large, they find that black holes in the early universe are much heavier relative to their host galaxies than they are today — a ratio of about $\frac{1}{30}$ as opposed to the current $\frac{1}{700}$.

Which came first?

What exactly does this mean? To Carilli, it means that the black hole forms first and the galaxy

forms around it. “That’s just an empirical statement,” he says. “The black hole is there and the galaxy is not — or at least there’s not much of it.”

Riechers puts it somewhat differently. “This doesn’t imply that black holes ‘seed’ galaxies,” he says. “They both can form at the same time, but they don’t grow at the same rate.” In the early going, the black hole grows at a faster rate because the way in which it grows, by accreting matter, is much more efficient than star formation. (A black hole can convert up to 40 percent of infalling matter into stored energy, but only a tiny percentage of the gas in a molecular cloud ends up in stars.)

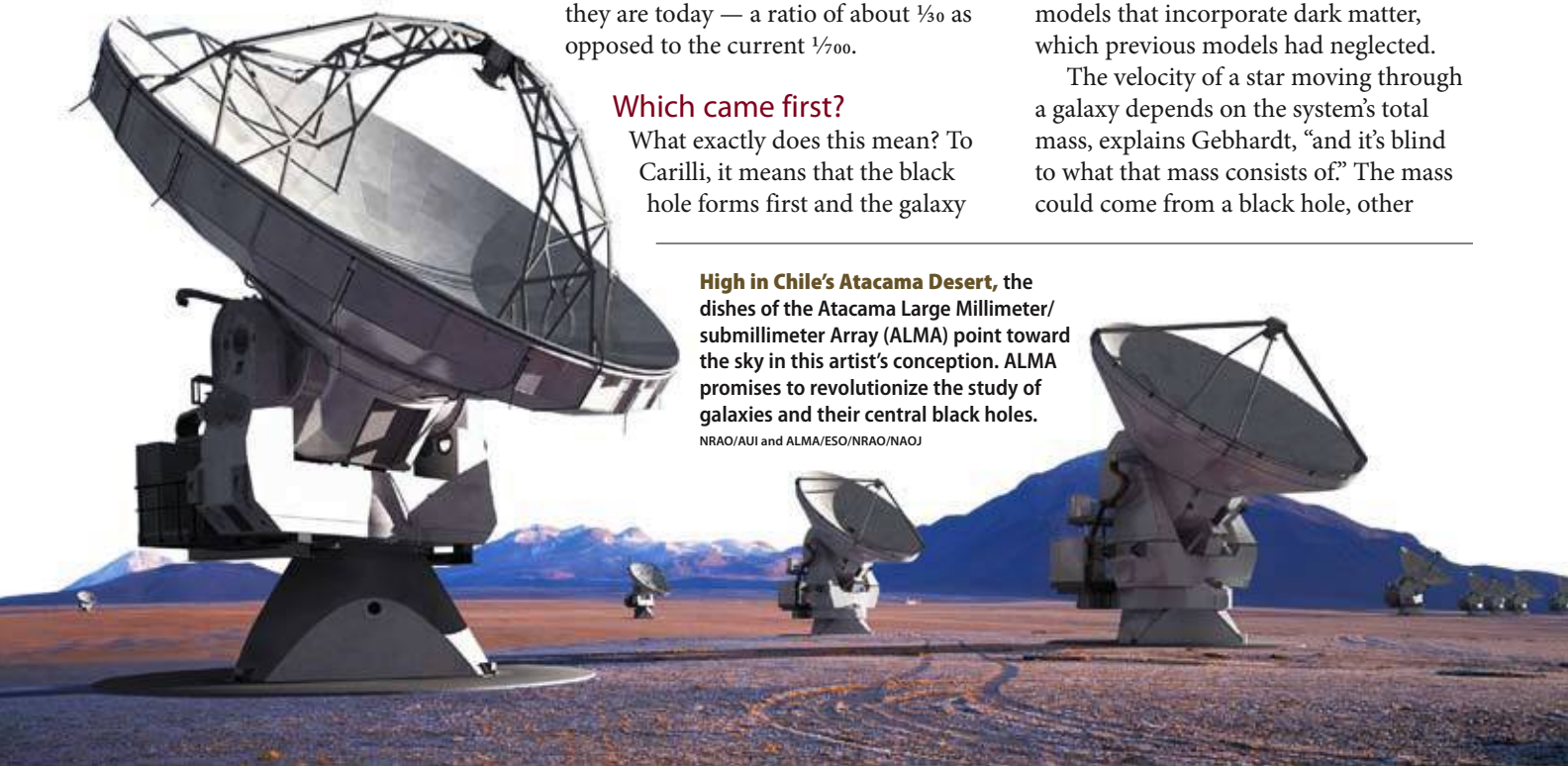
Their data suggest that black hole growth peaks early, whereas galaxies continue to grow longer. Regardless of the words used to express their finding, says Riechers, “it’s so new that there’s not yet a good theory to account for it.”

As if things weren’t confusing enough, even the masses of giant black holes now seem to be up for grabs. In 2009, Gebhardt, Jens Thomas of the Max Planck Institute for Extraterrestrial Physics, and University of Texas astronomer Juntai Shen analyzed the masses of the central black holes in M87 and M60, two large galaxies in the Virgo cluster. The team found that astronomers may have underestimated the masses by a factor of two and suggests that similar revisions may be necessary for most, if not all, super-massive black holes in large galaxies. The upwardly revised figures come from using models that incorporate dark matter, which previous models had neglected.

The velocity of a star moving through a galaxy depends on the system’s total mass, explains Gebhardt, “and it’s blind to what that mass consists of.” The mass could come from a black hole, other

High in Chile’s Atacama Desert, the dishes of the Atacama Large Millimeter/submillimeter Array (ALMA) point toward the sky in this artist’s conception. ALMA promises to revolutionize the study of galaxies and their central black holes.

NRAO/AUI and ALMA/ESO/NRAO/NAOJ





The relatively nearby quasar HE 0450–2958 (at center) appears to be shooting matter and energy into a bright gas cloud (upper left), triggering a burst of star formation. In this way, the central black hole may be building its own host galaxy. NASA/ESA/ESO/F. Courbin and P. Magain

stars, or an invisible halo of dark matter. If you don't take dark matter into account, says Gebhardt, "you figure the mass has to come from somewhere, with the natural tendency being to stick it in stars." But when the models include dark matter, the mass attributed to stars goes down. This increases the black-hole-to-galaxy mass ratio as well as the black hole's mass.

Increasing the central black hole's mass increases the amount of energy it can throw off; this, in turn, amplifies the effect the black hole can have on its host galaxy. Changing the black hole's mass, in other words, changes how the black hole relates to its galaxy. It will take a new physical model to incorporate this change, says Gebhardt.

Heading in the right direction

Richstone regards the current state of affairs as an "interesting mess." Scientists are learning plenty of new things, and some of them might lead to an answer, he says. "There's a lot of ferment right now, but no fine wine."

Few astronomers in the field find reason for despair. "We shouldn't throw out the baby with the bathwater," Schawinski cautions. "Coevolution may be more subtle than we once imagined it, and the how, when, and why may be more complex." But in many ways, the term still makes sense. Every large galaxy seems to have a black hole in the middle, so there has to be some connection between these things.

This especially holds true considering the energies involved. Accreting black holes are the most luminous things in the universe. The energy liberated by a super-



NASA/ESA/K. Cook (LLNL)

Dusty spiral arms wrap around NGC 4921's central bulge and the supermassive black hole that lurks inside. Astronomers still don't fully understand the relation between galaxy bulges and black holes.

massive black hole growing in a galaxy's core easily could blow apart its host. And even a tiny fraction of that energy can transform the galaxy. All of this argues that the fates of black holes and galaxies are bound together, even if astronomers can't yet spell out how that binding works.

Many researchers think future observations hold the key for sorting all this out. Gebhardt, for instance, is trying to see whether the apparent underestimate of black hole masses applies only to the giant black holes they've studied so far or to smaller ones as well. Schawinski and his colleagues aim to add more black holes and host galaxies to their sample while simultaneously pushing toward more distant galaxies.

Carilli, meanwhile, expects big things to come from the upgraded Expanded Very Large Array and the Atacama Large Millimeter/submillimeter Array (ALMA), both of which should be operating within a few years. ALMA "may represent the largest single step ever made in ground-based astronomy in any wavelength," he says. "Sensitivity, spatial resolution, and pretty much everything else will go up by two orders of magnitude, which means we'll be able to do for large numbers of

galaxies what we're now doing for just three or four."

And new studies keep the pot bubbling. In November 2009, David Elbaz of CEA Saclay in France and Knud Jahnke of Germany's Max Planck Institute for Astronomy reported on observations of a relatively nearby quasar, HE 0450–2958. They found that the quasar appears to be building its own host galaxy, spurring star formation by injecting matter and energy into a nearby gas cloud. In this version of the "chicken or the egg" question, the black hole comes first.

Despite the grand hopes from nearly 2 decades ago, the story hasn't yet reached a conclusion. After all the twists and turns they've encountered along the way, investigators hoping to solve this mystery should prepare for the surprises nature inevitably will throw in their paths.

As the Danish scientist and poet Piet Hein once wrote: "Problems worthy of attack prove their worth by hitting back." And if we've learned anything about black holes, it's that when they hit back, they do so with a vengeance. ☛



View a simulation of a massive galaxy cluster at www.Astronomy.com/toc.

THE NEW SEARCH FOR LIFE IN THE UNIVERSE

Astrobiologist **Christopher Chyba** tells the inside story of how astronomers are searching for other life.

For thousands of years, people have wondered if there are other worlds like Earth that support living organisms. Soon, instead of speculating, we should know what fraction of stars host earthlike planets, at least in our neighborhood of the Milky Way Galaxy.

The fabulous thing about the search for extraterrestrial life today is that we are beginning to answer the important questions. Using ground-based telescopic observations, we have already learned that planets in general are not rare — more than 10 percent of Sun-like stars appear to have solar systems, and that fraction could prove to be much higher. So far, because of selection effects, our searches have been biased toward detecting giant planets orbiting close to their suns. But our most advanced searches are now shedding this bias, and we will soon know whether planets as small as Earth are common.

Planetary detection from ground-based telescopes is continuously becoming more sensitive, but it will likely be NASA's Kepler mission that tells us over the coming few years how common Earth-sized planets are. Kepler is a spacecraft in orbit around the Sun that constantly stares at 100,000 stars for signs of planets. (It looks for a star to periodically dim as a result of its planet passing in front of it.) Once it finds a planet, Kepler will determine the distance of that world from its star.

The craft will take several years to discover earthlike worlds (should they exist) and to determine what fraction of these planets orbit within their stars' habitable zones. Such zones differ in size; they vary for different types of stars. Within habitable zones, planets could have liquid water oceans on their surfaces.

Christopher Chyba is a professor of astrophysics and international affairs at Princeton University. He serves on the Committee on International Security and Arms Control of the National Academy of Sciences and on the President's Council of Advisors on Science and Technology.

This is why Kepler is on a very short list of space missions that are milestones in human history. Unfortunately, too much of the public seems unaware of Kepler. We must not let our civilization sleepwalk through this important transition in our understanding of our place in the universe.

Life's start

Our understanding of life on Earth is exploding. We are continuously learning more about microscopic life's ability to withstand what we consider extreme environments and the demands such locations place on that life. These environments and microbes can serve as models — albeit Earth-centric ones — for life elsewhere.

At the same time, our understanding of how life originated on Earth inches forward. This question has turned out to be difficult to answer, but in the past generation it has gone from a small research interest with little funding (mostly from NASA) to a much more widely recognized field. And advances in computation, biotechnology, and laboratory robotics offer new hope for progress.

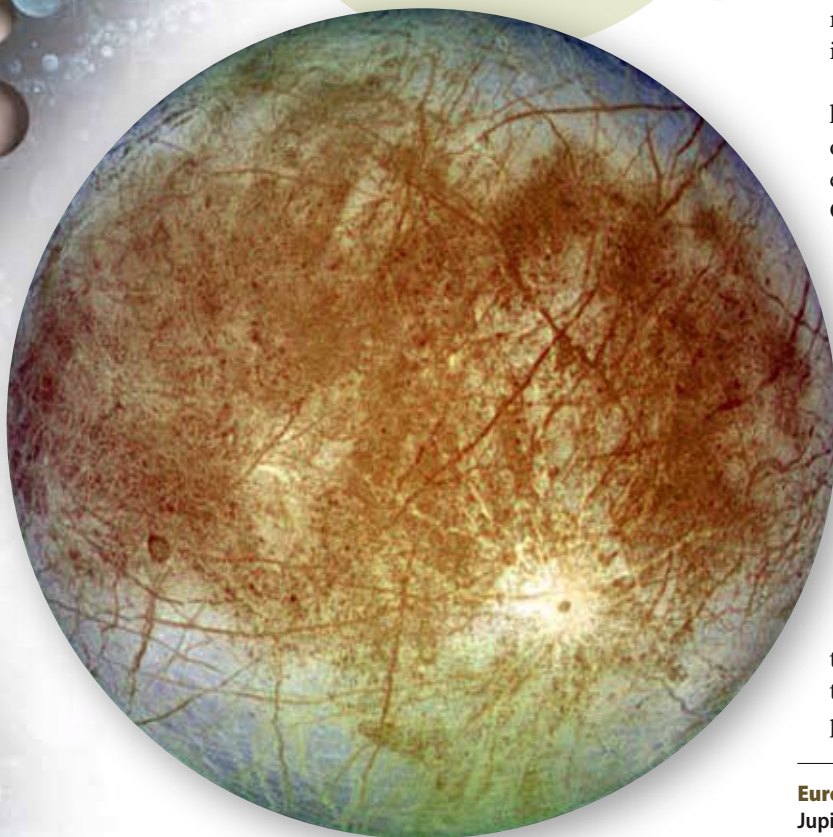
Comet and asteroid bombardment played a large role in the history of life on Earth. What we know about the bombardment histories of Earth and the inner planets remains surprisingly incomplete, and further studies of the lunar surface could go far toward filling in the gaps. Most of our knowledge comes from the Apollo and Luna (Soviet spacecraft) explorations of the Moon, along with studies of lunar meteorites that have fallen on Earth. While science didn't drive the Moon race, what we found at the Moon nevertheless had tremendous influence on our understanding of the role of impacts on Earth life. Many nations, including the United States, are now returning to the Moon with robotic spacecraft.

Liquid water in the solar system?

One important conclusion from the study of life on Earth is the absolute

Astrobiology ties together many different areas of science: extrasolar planets, the origin and evolution of life, chemistry, and the life cycles of stars. Scientists use their knowledge about these different areas to learn about life in the universe.

Europa's ocean
may be habitable
for some Earth
microorganisms
— despite being
covered by miles
of ice.



requirement for liquid water. Of course, it's possible to imagine a form of life based on some other solvent — even a radically different solvent like a hydrocarbon, such as methane. Were this possible, the surface of Saturn's moon Titan, with its strangely earthlike meteorological cycle of methane, would be even more interesting. But at this stage in our limited knowledge of what is biologically possible, it makes sense to focus first on life as we know it. So we study places that could provide liquid water environments for life today — or that may have in the past.

It now seems likely that subsurface liquid water oceans are common in the outer solar system, although not all are of equal biological interest. Jupiter's moons Ganymede and Callisto appear to have oceans trapped between two layers of different types of ice. These oceans lack the potentially important chemical activity of water interacting with rock, and thus seem unlikely to provide biologically interesting environments.

Jupiter's moon Europa, on the other hand, has an ocean of liquid water below a cover of ice. The water's volume appears to be twice that of Earth's oceans combined, and its chemistry is much more intriguing. At its bottom, the ocean's floor is in contact with Europa's rocky mantle. At its top, it is in contact with the chemical products in its ice cover. Charged par-

Europa experiences a gravitational tug-of-war from Jupiter. These tidal interactions stretch and crack Europa's surface ice. NASA/JPL/DLR

Taking the historical perspective on astrobiology

In 1941, philosopher Laurence Lafleur defined astrobiology as "the consideration of life in the universe elsewhere than on Earth." But today, scientists in the field of astrobiology reject this distinction between the study of life elsewhere and the study of life on our planet.

Our understanding of the origin and evolution of life on Earth is intricately tied to our modern knowledge of the Sun and solar system; and our rap-

idly growing comprehension of life on Earth, especially in extreme environments, strongly relates to the search for life elsewhere. Recognizing these connections, the NASA Astrobiology Institute calls astrobiology "the study of the living universe," making no distinction between life here or out there.

That unification is here to stay. Much of the excitement in astrobiology today comes from how studies of life on Earth con-

nect to the exploration of nearby worlds. Scientists know life exists in extreme environments on Earth. This knowledge provides models for possible ecosystems on Mars and Jupiter's moon Europa. Scientists also work on understanding our Moon's ancient cratering record, which tells us about Earth's own early bombardment history, some of Earth's oldest rocks, and primitive life on our planet. — C. C.

Oceans under the surface



Three of Jupiter's moons harbor oceans under their surfaces. Europa's ocean flows between a layer of ice and a rocky mantle. Minerals from the rock layer and heat from hydrothermal vents on the mantle surface may create an environment suitable for life. Ganymede's and Callisto's oceans, however, sit between layers of ice and thus likely don't have the right temperatures and chemistry needed for life. NASA

ticles accelerated by Jupiter's magnetic field interact with the ice to produce molecules like oxygen and probably even formaldehyde.

Europa's ocean may be habitable for some Earth microorganisms — despite being covered by miles of ice. But habitability for life doesn't necessarily imply a good environment for the origin of life. The only way we will know if Europa's ocean hosts life is by going there. If there is life on Europa, it likely (but not certainly) stems from an independent origin of life from that on Earth. The knowledge we would glean from its characterization would be staggering.

One of the most exciting missions of the coming decades is the Europa Jupiter System Mission (EJSM), which could launch in 2020 and reach the Jupiter system around 2025. EJSM will probably not determine whether life exists on Europa, but it is the necessary next step toward knowing for sure.

Our important neighbor

And then, of course, there is Mars. The Red Planet clearly had a great deal of liquid water on its surface billions of years ago, and it likely has subsurface liquid water today. That water may even now occasionally reach the martian surface, and any such locations would rank among the most exciting, and certainly the most accessible, spots in the solar system to search for extraterrestrial life.

Surface missions to these locations will also put rigid requirements on space-

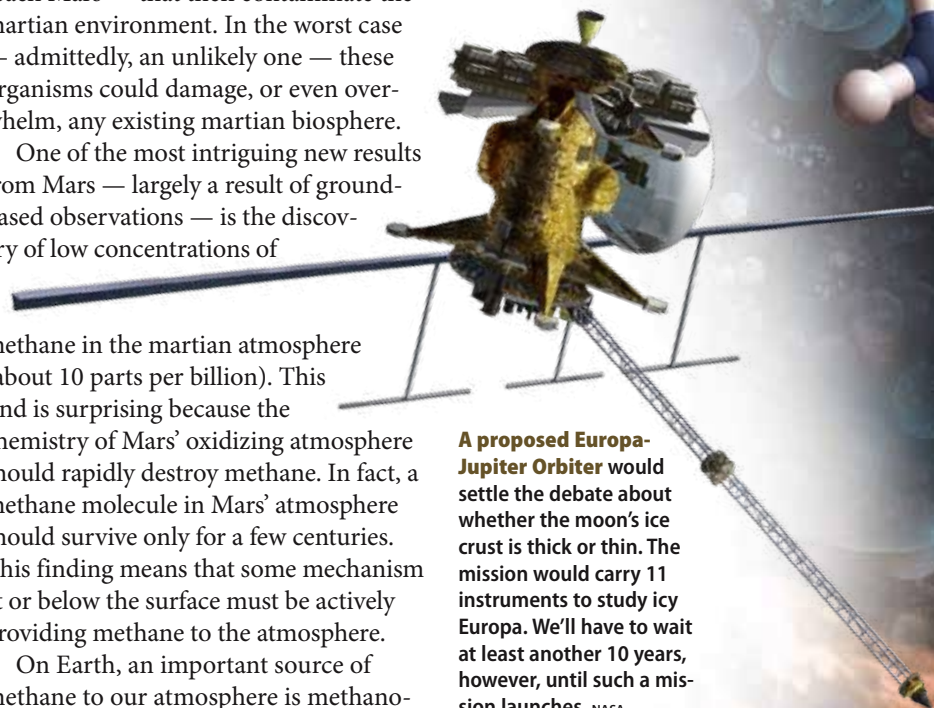
craft sterility. We must ensure that we do not carry microorganisms from Earth — which we know from orbiting space missions can survive long enough in space to reach Mars — that then contaminate the martian environment. In the worst case — admittedly, an unlikely one — these organisms could damage, or even overwhelm, any existing martian biosphere.

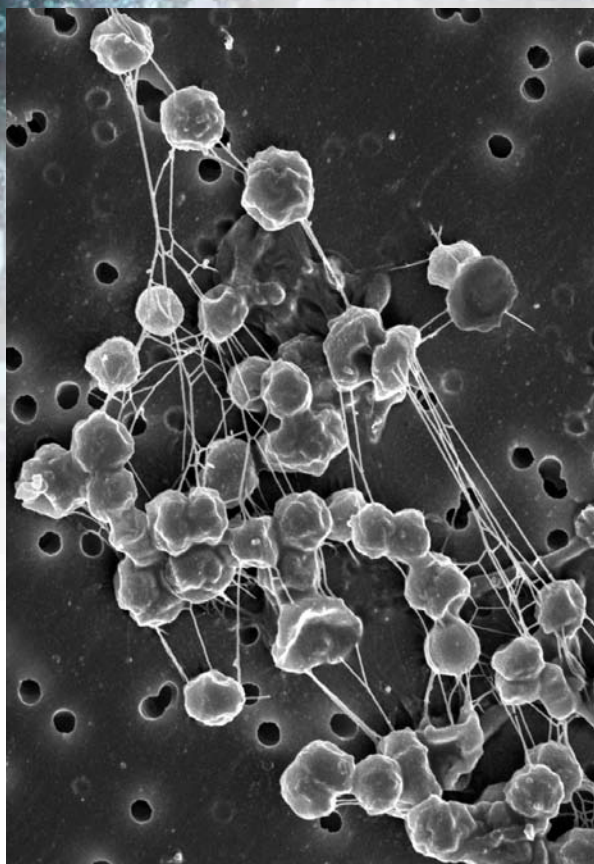
One of the most intriguing new results from Mars — largely a result of ground-based observations — is the discovery of low concentrations of

methane in the martian atmosphere (about 10 parts per billion). This find is surprising because the chemistry of Mars' oxidizing atmosphere should rapidly destroy methane. In fact, a methane molecule in Mars' atmosphere should survive only for a few centuries. This finding means that some mechanism at or below the surface must be actively providing methane to the atmosphere.

On Earth, an important source of methane to our atmosphere is methanogenic (methane-producing) bacteria. The methane in Mars' atmosphere, which varies from location to location, as well as seasonally, is therefore of great interest biologically. But volcanoes can release methane gas, and reactions between water and carbon dioxide could produce methane underground. Right now scientists have no way to differentiate between the biological and geochemical hypotheses. However, further ground-based

A proposed Europa-Jupiter Orbiter would settle the debate about whether the moon's ice crust is thick or thin. The mission would carry 11 instruments to study icy Europa. We'll have to wait at least another 10 years, however, until such a mission launches. NASA





Methane-producing microbes, called “methanogens,” could live below the martian surface and contribute to the methane found in the planet’s atmosphere. Other processes, however, could instead contribute to the tiny amount of methane. Maryland Astrobiology Consortium/NASA/ STScI



The Allen Telescope Array (ATA) is a radio astronomy project currently in the works. In addition to studying our galaxy, gamma-ray bursts, and other astronomical targets, the ATA searches for signals of intelligent, extraterrestrial origin. Seth Shostak/SETI Institute

observations and the demanding data reduction required to interpret the martian atmosphere while looking through our own atmosphere, as well as future spacecraft observations, should soon tell us much more.

In the meantime, our inability to rule in or out biology as a cause of the martian methane is a sobering warning about our capacity in the future to infer the presence of life about some distant exoplanet from a telescopic analysis of its atmosphere. We know so much more about Mars than we may ever know about any exoplanet, but we cannot yet determine whether biology or geochemistry produces the atmospheric methane.

How intelligence fits in

An altogether different way to search for life off Earth is to look for extraterrestrial technology — usually called SETI.

We have had a century of debates about whether intelligence should be common or rare in the universe, with impressively confident answers proposed on both sides. It is time to enrich this debate with further data. This can be done first by increasing funding and conducting a bolder search program.

The SETI Institute and the University of California at Berkeley are just starting an ambitious project using the nascent Allen Telescope Array. Unfortunately, the project hasn’t secured enough funding to fill out the array from its current 42 telescopes to its planned 350. Yet the amount of needed funding is small compared to spacecraft missions to the planets. The stakes are high, so it seems unimaginable that our civilization cannot make this project happen.

A second way to add data to the argument can come from continuing rigorous studies of the evolution of animal intelligence on Earth, similar to what Lori Marino of Emory University, Daniel McShea of Duke University, and Mark Uhen of George Mason University have pioneered with support from the SETI Institute. These researchers investigated the fossil record of brain-growth in toothed whales (a suborder which includes dolphins), and showed that the evolution of intelligence in this one case seemed to follow a random-walk pattern, with no particular driver toward greater brain size. Yet, over time, three species of

Protect the science or the planet, that is the question

Scientists use planetary protection, a space-age discipline, to prevent two types of contamination: forward (microbes carried on spacecraft from Earth contaminating other worlds) and back (alien microbes on spacecraft returning from those worlds to Earth). Researchers assemble spacecraft in clean rooms, but there are still thousands of spores — especially hardened, self-protecting forms of some microbes — per square foot of spacecraft surface, and probably hundreds of times more of other microbes.

We know that some of these microbes — especially the spores — can survive years in space, as long as they are shielded from solar ultraviolet light. Any microbe inside a spacecraft would be protected from such radiation. Planetary protection is therefore a difficult problem.

Ever since the Nobel Prize-winning biologist Joshua Lederberg first raised the issue of planetary protection more than half a century ago, the focus of this effort has been on “protecting the science” of space explo-



Planetary protection requirements for the Mars Science Laboratory, launching in 2011, are stricter than previous missions. NASA/JPL-Caltech

ration. In 1967, the Outer Space Treaty entered into force. Article IX of the treaty demands that space-faring nations avoid the “harmful contamination” of other worlds. But harmful to whom? The answer has been: Harmful to the nations that have signed the treaty because they have a stake in not having their biological investigations confused by forward contamination. If microbes are carried into extraterrestrial environments, they might confound future efforts to determine what alien microbes might be present.

A few years ago, I chaired a committee of the National Re-

search Council that called for an international conference to consider whether we should expand our understanding of planetary protection. Is this traditional “protecting the science” understanding of preventing forward contamination adequate? Or do we need a broader purpose, such as “protecting the planet”? Do we have a responsibility to protect possible alien biospheres, regardless of whether our scientific investigations may be put at risk? It is time to address this question, including the implications for cost and mission difficulty that any such changes may require. — C. C.

toothed whales nevertheless became the second-brainiest creatures on the planet, right behind human beings.

This kind of careful work needs to be extended to more examples in the animal kingdom before we can draw confident conclusions about the mechanisms of the evolution of intelligence. Such work will almost certainly require private funding — and that is largely lacking.

Astrobiology is a field in explosion, knocking at the door of major discoveries. And if we want to thoroughly study the living universe, researchers need to contemplate not only questions of origins and evolution, but also those of the evolution and fate of civilizations. For civilization is one possible, and especially precious, result of biology. ▀



A team of scientists studied brain scans of toothed whales (a suborder that includes dolphins) over a 50-million-year history. Through this study, the team learned how intelligence evolved and led to toothed whales becoming the second-brainiest animals on Earth. A fiber stain of a dolphin brain is shown above. Michigan State University Brain Biodiversity Bank/National Science Foundation



Learn about life at Earth's extreme environments at www.Astronomy.com/toc.



The Sky this Month

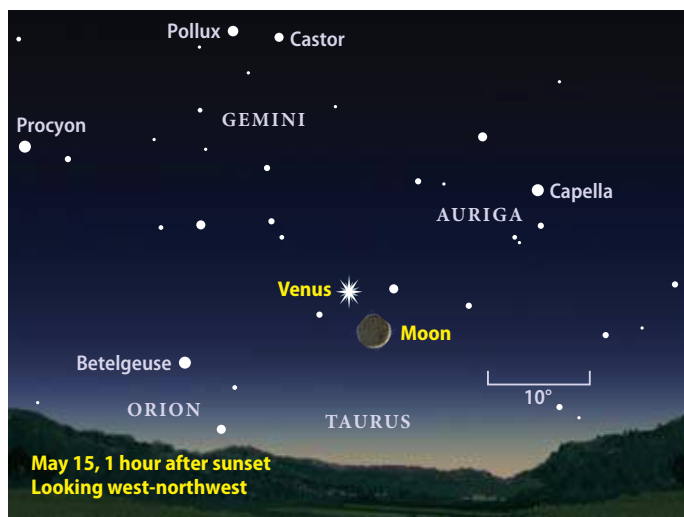
Martin Ratcliffe and Alister Ling describe the solar system's changing landscape as it appears in Earth's sky.

May 2010

Spend an evening with Venus



Seeing Venus near a crescent Moon always brings a thrill. The two met each other in December 2008 (seen here) and will do so again this month. Robert Slobins



A slim crescent Moon points toward Venus in evening twilight May 15. The two lie among the background stars of Taurus the Bull. Astronomy: Roen Kelly

The relatively short nights of late spring don't hinder planet observers this year. May provides six well-placed planets for your viewing pleasure. Venus, Mars, and Saturn populate the evening sky, and the latter two remain on display until well past midnight. Three other planets — Jupiter, Uranus, and Neptune — gather in the predawn sky.

Look to the west after sunset, and you can't miss **Venus**. The brightest point of light in the sky shines at magnitude -3.9 and stands nearly 20° above the horizon 45 minutes after sunset. It remains on view until after 10 P.M. local daylight time. Venus lies among the background stars of Taurus the Bull during the first part of May, then moves into Gemini the Twins on the 20th.

The bright star to Venus' lower left early this month is Aldebaran, the 1st-magnitude luminary of Taurus. The planet passes 6° north of the star May 3.

To naked eyes and through binoculars, Venus always looks enticing. Through a telescope, however, Venus puts on a grand show only when it comes close to Earth. Now is not that time. On May 1, Venus spans $11''$ and shows a fat gibbous disk (89 percent lit). By late in the month, the disk has grown to $13''$ and the phase has shrunk to 81 percent illumination. This trend indicates that Venus is moving slowly closer to us. You can expect much nicer telescopic views by late summer.

Venus and a nearby crescent Moon create photogenic moments nearly every month, and May is no exception. Such scenes are evocative, easy to capture with a digital camera, and enhanced by foreground silhouettes. On May 15, you'll find a slim crescent Moon whose horns point up toward the two stars that mark the horns of Taurus the Bull: Beta (β) and Zeta (ζ) Tauri. Slightly above the midway point between this stellar pair sits brilliant Venus. You'll have about 40 minutes to photograph the scene against a rapidly changing twilight sky.

The symmetry is broken the next evening (May 16), although the grouping still

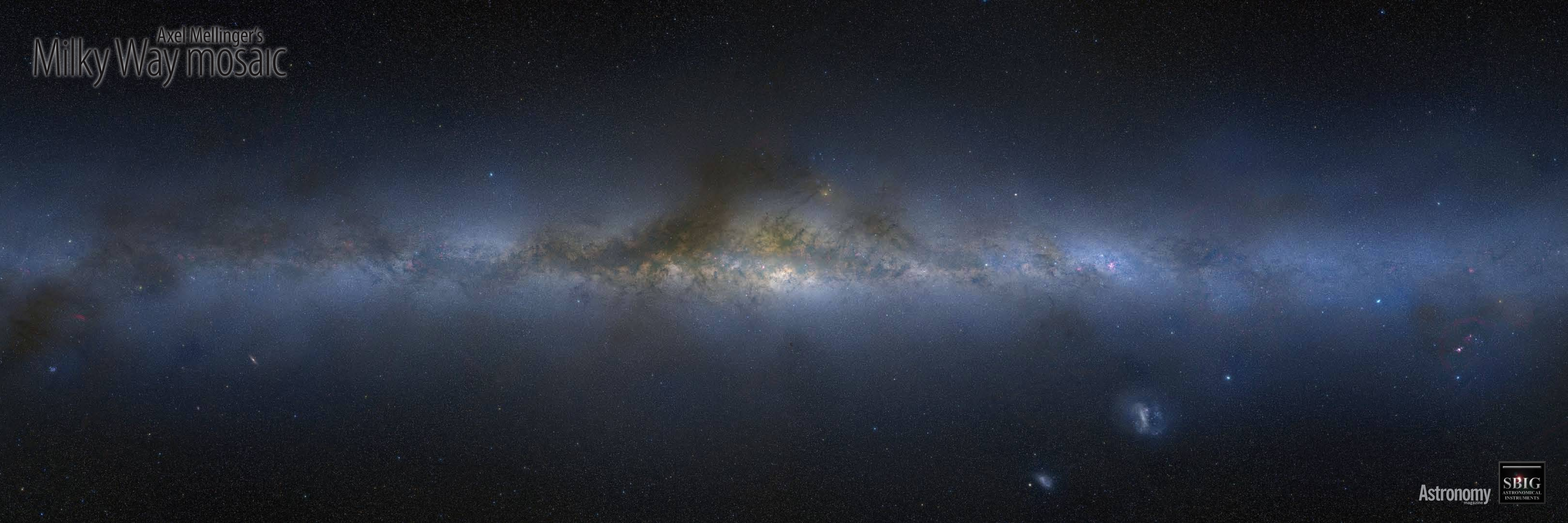
40	The Moon visits Venus	
53	Meteor watch	
53	Rising Moon	
54	When to view the planets	  
54	Rhea meets Titan	
54	Comet search	
55	Locating asteroids	 
55	Saturn's Maiden voyage	  
 Visible to the naked eye		
 Visible with binoculars		
 Visible with a telescope		

looks attractive. The crescent Moon, which resembles the Cheshire Cat's grin, stands 8° to Venus' upper left. The Moon is long gone by May 27, when Venus lies against the backdrop of Gemini. Keen-eyed observers might spot the 3rd-magnitude star Mebsuta (Epsilon [ϵ] Geminorum) a single Moon-width above the brilliant planet.

Mars and Saturn come into view as soon as the sky starts to darken, about 30 minutes after sunset. On May 1, Saturn lies 110° from Venus with Mars roughly halfway between. The combined motions of Earth and these three planets around the Sun cause this angle to shrink as May progresses. The trio reaches an angular separation

— Continued on page 53

Axel Mellinger's
Milky Way mosaic



Axel Mellinger's Milky Way mosaic

An amateur astronomer captures our galaxy
in glorious detail. by Michael E. Bakich

This Milky Way image (reproduced to a larger scale on this poster's other side) represents a long-term project by Axel Mellinger, professor of physics at Central Michigan University. Mellinger combined images from 70 different fields of view, each of which measured 40° by 27°. To ensure a seamless mosaic, he overlapped adjacent fields by at least 15 percent.

Mellinger began shooting in October 2007 and finished in August 2009. He shot from two locations in South Africa for the fields centered on declinations -90°, -62°, -32°, and 0°. For the northern fields centered on declinations 32°, 62°, and 90°, he used four locations in Texas and three in Michigan.

He coupled a 50mm Minolta MD f/1.4 lens to a Santa Barbara Instrument Group STL-11000 CCD camera. To improve photographic quality, Mellinger stopped the lens down to f/4 for all exposures. Fields were combinations of photos taken through red, green, and blue filters.

To increase the picture's dynamic range, Mellinger combined three different exposure times: 0.5, 15, and 240 seconds. He took five frames at each exposure time through each filter. A little math shows that's a total of 3,150 photos for the entire panorama. The final image scale is 36" per pixel, the



Axel Mellinger displays the photographic system he used to capture more than 3,000 images for his Milky Way panorama. Axel Mellinger

limiting magnitude is 14, and the entire mosaic measures 36,000 pixels by 18,000 pixels, a total of 648 megapixels.

After acquiring the exposures, Mellinger had to process them into a cohesive whole. One problem he faced was removing nearby contributions to night sky brightness. They included light pollution, airglow, and the zodiacal light. Moreover, he had to retain contributions from unresolved stars, diffuse galactic light, and the extragalactic background, which is light from unseen galaxies.

He separated the unwanted light by using space-borne visual photometry data from the Imaging Photopolarimeters aboard the Pioneer 10 and Pioneer 11 space probes. Those instruments provided measurements of the "good" background glow. Mellinger then used simple subtraction to remove the "bad" glow. Mellinger expects this panorama to be a valuable educational tool. He also recognizes its scientific value, providing high-quality surface photometry (brightness measurements) of the Milky Way. At *Astronomy* magazine, we recognized one other trait: The image is gorgeous — and we're delighted that Mellinger shared it with our readers.

Michael E. Bakich is an *Astronomy* senior editor.

Astronomy
magazine



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The California Nebula (NGC 1499) glows because of radiation given off by the magnitude 4.0 star Menkib (Xi [ξ] Persei), which sits 0.2° south of the nebula. Conrad Pope



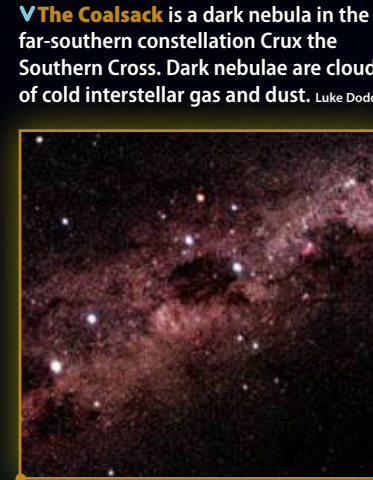
The North America Nebula (NGC 7000) lies only 3° east of Deneb (Alpha [α] Cygni). From a dark site, sharp-eyed observers can see this stunning object with their naked eyes. Neil Fleming



<The sky around Antares (the yellow star at the lower left of center) contains globular clusters, wide swaths of dark nebulosity, and the spectacularly colored Rho Ophiuchi region. Jason Ware



>Omega Centauri (NGC 5139) is our galaxy's largest globular cluster. It appears slightly larger than the Full Moon, shines at magnitude 3.5, and contains some 10 million stars. NASA/ESA/Hubble Heritage Team (STScI/AURA)



▼The Coalsack is a dark nebula in the far-southern constellation Crux the Southern Cross. Dark nebulae are clouds of cold interstellar gas and dust. Luke Dodd



The Eta Carinae Nebula (NGC 3372) is a gas cloud, nearly a light-year long, expanding at 1.5 million mph (2.3 million km/h). Within the cloud sits one of the galaxy's most massive stars radiating 5 million times the Sun's energy. NASA/ESA/N. Smith (Univ. of California, Berkeley)/Hubble Heritage Team (STScI/AURA/NOAO/AURA/NSF)



Sirius (Alpha Canis Majoris) is the brightest star in our night sky. It shines at magnitude -1.47, twice as luminous as the next-brightest star, Canopus (Alpha Carinae). NASA/H.E. Bond and E. Nelan (STScI)/M. Barstow and M. Barleigh (Univ. of Leicester)/J. B. Holberg (Univ. of Arizona)



The Orion Nebula (M42) is the sky's second-brightest nebula. From a dark site, sharp-eyed observers can detect this cloudy patch without optical aid as the central "star" in Orion the Hunter's sword. Telescopes show the full extent of this object, which covers an area 6 times the size of the Full Moon. NASA/ESA/M. Robberto (STScI/ESA) and the Hubble Space Telescope Orion Treasury Project Team



The Pleiades (M45) in Taurus the Bull is the sky's brightest star cluster. More than 300 stars form this group, which lies some 440 light-years away. NASA/ESA/AURA/Caltech



The Andromeda Galaxy (M31) gets its familiar name from the northern constellation where it resides, Andromeda the Princess. M31 lies at the far end of the Local Group of galaxies, which includes the Milky Way. Tony Hallas



The galactic center from Earth's point of view resides in the constellation Sagittarius the Archer. To find the center of our Milky Way's celestial coordinates, look for right ascension 17h45m, declination -28°43' on a star chart. Bill and Sally Fletcher



Rigel Kentaurus is a triple star also known as Alpha Centauri. This star is the third-brightest in the sky and the closest system to Earth. Its closest component lies 4.2 light-years away. Marco Lorenzi



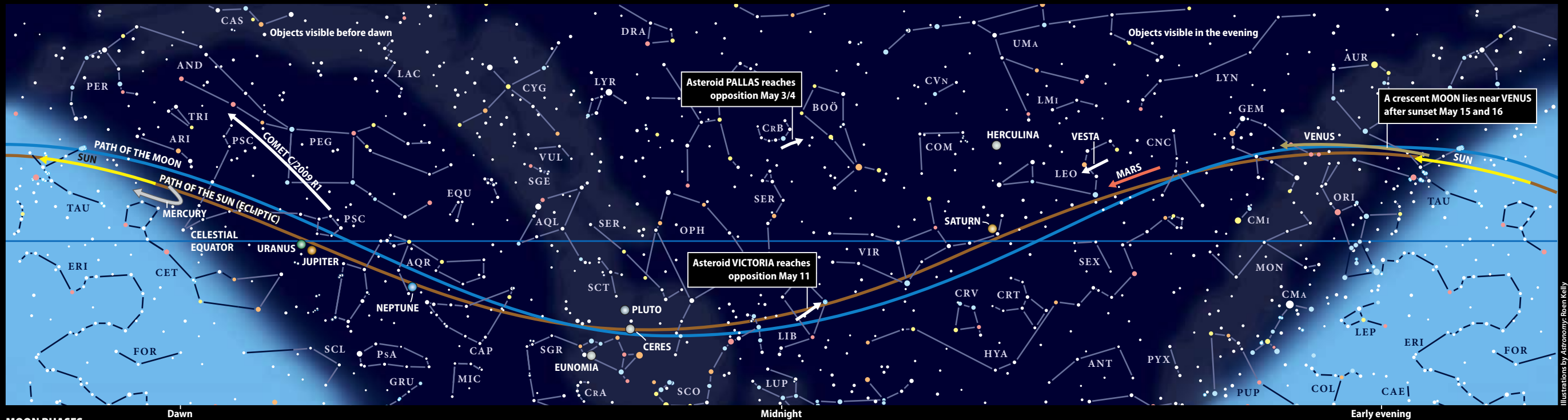
<The Small Magellanic Cloud lies in Tucana. It's the sky's second-largest galaxy by apparent size. It measures 5.3° by 3.1°. Its stars combine to give off the light of a magnitude 2.7 star. Thomas V. Davis



>The Large Magellanic Cloud lies in the constellation Dorado the Swordfish. It measures a massive 10.8° by 9.2°. The light we see equals the output of a magnitude 0.4 star. Andreas B'ker and Axel Martin

Planets in May 2010

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



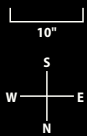
MOON PHASES

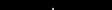
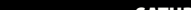


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line. **Note:** Moons vary in size due to distance from Earth and are shown at 0h Universal Time.



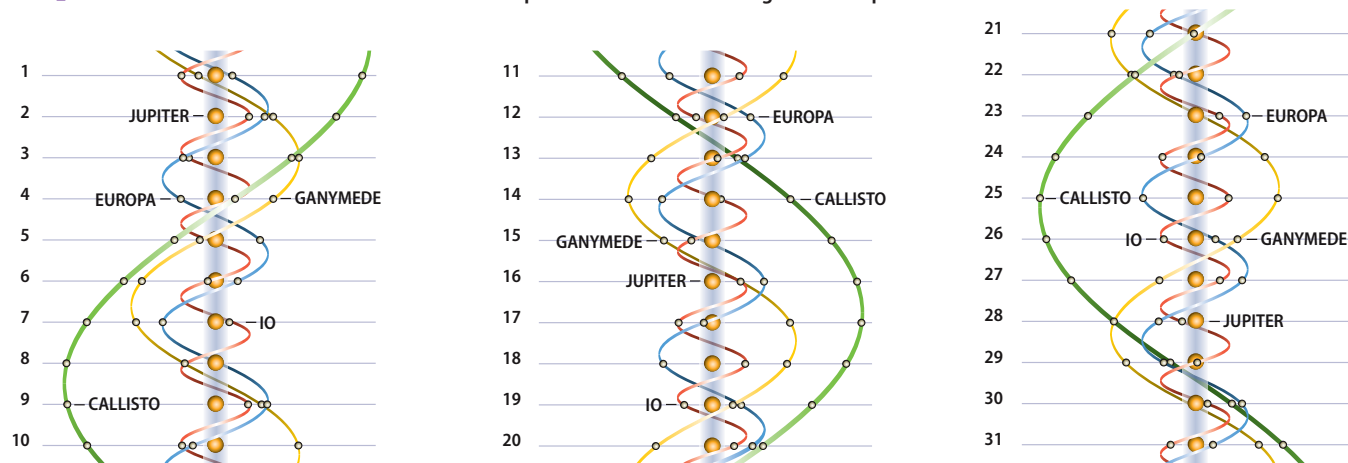
PLANETS



PLANETS		MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date										
Magnitude		0.1	-3.9	0.9	7.9	-2.2	0.9	5.9	7.9	14.0
Angular size		7.4"	12.0"	6.6"	0.7"	36.2"	18.6"	3.4"	2.3"	0.1"
Illumination		48%	86%	90%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth		0.906	1.388	1.412	1.962	5.443	8.914	20.665	30.084	31.066
Distance (AU) from Sun		0.420	0.718	1.656	2.815	4.976	9.516	20.095	30.021	31.833
Right ascension (2000.0)		2h54.2m	5h32.7m	9h25.6m	18h16.0m	23h48.2m	11h56.2m	23h59.0m	22h03.2m	18h20.6m
Declination (2000.0)		13°15'	24°40'	16°58'	-23°23'	-2°28'	3°07'	-0°54'	-12°26'	-18°12'

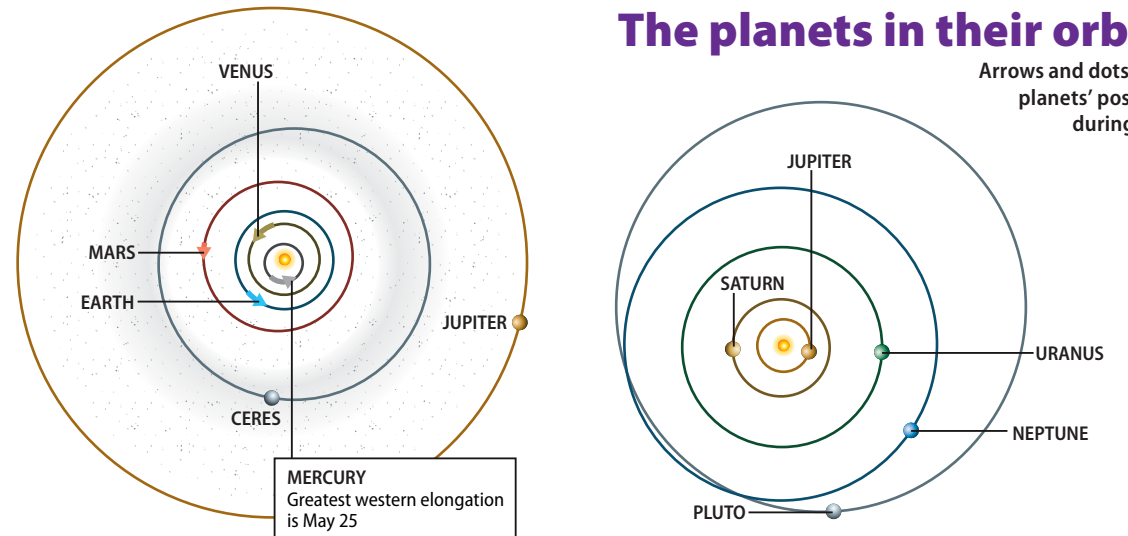
Jupiter's moons

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



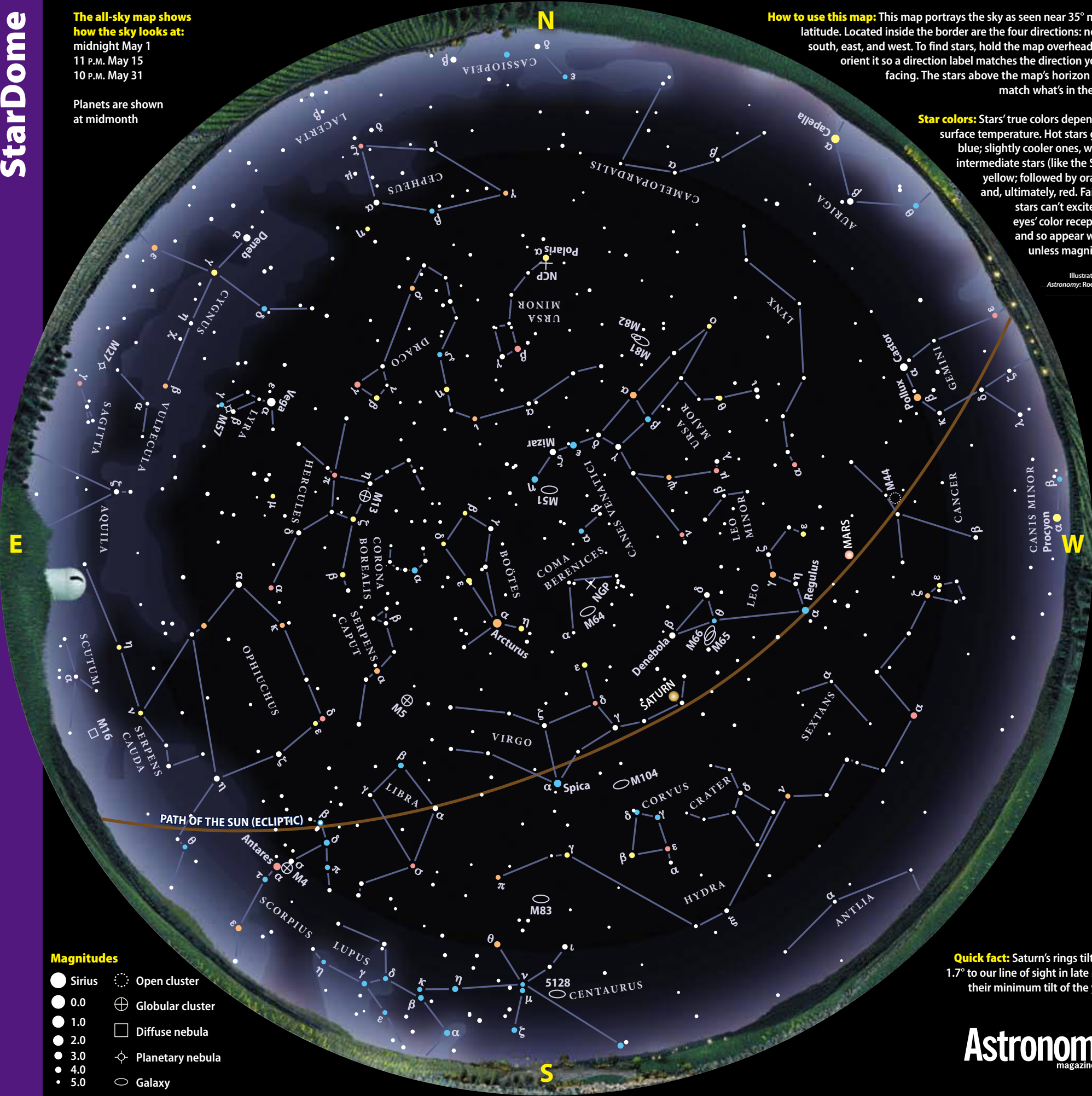
The planets in their orbits

Arrows and dots show planets' positions during May.



The all-sky map shows how the sky looks at: midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth



How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Star colors: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by Astronomy: Roen Kelly

- Magnitudes**
- Sirius
 - 0.0
 - 1.0
 - 2.0
 - 3.0
 - 4.0
 - 5.0
 - Open cluster
 - ⊕ Globular cluster
 - Diffuse nebula
 - ⊛ Planetary nebula
 - Galaxy

Quick fact: Saturn's rings tilt just 1.7° to our line of sight in late May, their minimum tilt of the year.

May 2010

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						 1
 2	 3	 4	 5	 6	 7	 8
 9	 10	 11	 12	 13	 14	 15
 16	 17	 18	 19	 20	 21	 22
 23	 24	 25	 26	 27	 28	 29
 30	 31					

Calendar of events

- 3** Asteroid Pallas is at opposition, midnight EDT

Venus passes 6° north of Aldebaran, midnight EDT
- 6**  Last Quarter Moon occurs at 12:15 A.M. EDT

Eta Aquarid meteor shower peaks

The Moon is at apogee (251,180 miles from Earth), 5:52 P.M. EDT
- 7** The Moon passes 4° north of Neptune, 6 A.M. EDT
- 9** The Moon passes 7° north of Jupiter, 2 P.M. EDT

The Moon passes 6° north of Uranus, 9 P.M. EDT
- 10** Mercury is stationary, 8 P.M. EDT
- 11** Asteroid Victoria is at opposition, 3 P.M. EDT
- 12** The Moon passes 8° north of Mercury, 1 P.M. EDT
- 13**  New Moon occurs at 9:04 P.M. EDT

Special observing date

- 15** After sunset this evening, look for the crescent Moon's horns pointing up toward brilliant Venus.
- 16** The Moon passes 0.08° north of Venus, 6 A.M. EDT
- 20** The Moon is at perigee (229,742 miles from Earth), 4:45 A.M. EDT

The Moon passes 5° south of Mars, 8 A.M. EDT

 First Quarter Moon occurs at 7:43 P.M. EDT
- 23** The Moon passes 8° south of Saturn, 1 A.M. EDT
- 25** Mercury is at greatest western elongation (25°), 10 P.M. EDT
- 27**  Full Moon occurs at 7:07 P.M. EDT
- 29** The Moon passes 0.09° south of asteroid Ceres, 6 P.M. EDT
- 31** Saturn is stationary, noon EDT

Neptune is stationary, 10 P.M. EDT

— Continued from page 40
of 90° — half the night sky —
May 17. By the 31st, the angle
has dropped to 74°.

Mars spends the month
crossing the generally bland
region between the figures of
Cancer the Crab and Leo the
Lion. On May 19, you'll find
Mars just above a fat crescent
Moon. By the 31st, the Red
Planet's eastward motion has
carried it to within 3° of Reg-
ulus, the brightest star in Leo.

Notice these two objects' color contrast. Mars' orange
cast arises from the color of its
surface rocks and soil while
Regulus' blue-white hue
comes from hot gases at its
visible surface. The brightness
contrast between the two is
less noticeable. Mars shines
at magnitude 1.1, just a shade
brighter than Regulus.

Observers who target Mars
with a telescope have their
work cut out for them. The
Red Planet now lies quite far

from Earth — some 130 mil-
lion miles in mid-May — and
thus appears small. Mars' disk
measures 7" across, so you'll
need a 12-inch or larger tele-
scope to see any appreciable
detail. The only obvious fea-
ture will be the white north
polar cap.

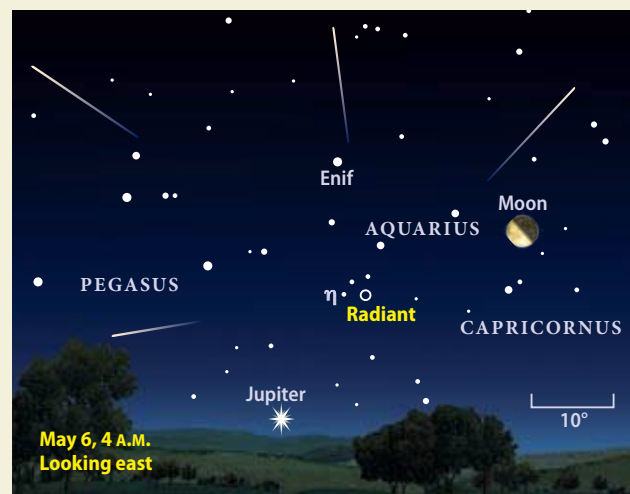
Although Mars will remain
bright for several more
months, the disk's diminish-
ing size renders telescopic
views disappointing at best.

Fortunately, **Saturn** makes
up for Mars' diminishing
appeal. The ringed planet
looks stunning through a tele-
scope and remains visible
nearly all night. You can find
it high in the south after sun-
set, a bit more than halfway
from the horizon to the
zenith. Saturn lies in western
Virgo, just a couple of degrees
northeast of 4th-magnitude
Beta Virginis.

The bright star to Saturn's
lower left is Spica, the lumi-
nary of Virgo the Maiden.
Spica shines at magnitude 1.0.
That is 0.2 magnitude fainter
than Saturn in early May, but
the planet fades slightly to
equal Spica by month's end.

When viewed through a
telescope, Saturn reveals thin

Meteor watch



The Eta Aquarid meteor shower peaks before dawn May 6. A Last Quarter Moon interferes with the view, but observers still should see 10 to 20 shooting stars per hour. Astronomy: Roen Kelly

Halley's debris lights up the sky

The annual Eta Aquarid meteor shower peaks the morning of May 6. A Last Quarter Moon then lies about 20° from the shower's radiant (the spot from which the meteors appear to originate) in the constellation Aquarius. Moonlight will drown out some fainter meteors and render the brighter ones a little less impressive.

For those who live near 40° north latitude, the radiant rises in the east around 2:30 A.M. local daylight time and climbs about 15° high by 4 A.M. Twilight begins to interfere soon thereafter, so the best views will come around 4 o'clock.

Astronomers say up to 85 Eta Aquarid meteors per hour could be visible if the radiant were overhead in a dark sky. But moonlight and the radiant's low altitude mean we'll likely see at most 20 per hour. Meteors occur when dust motes get incinerated in Earth's atmosphere. For the Eta Aquarids, the dust comes from material Comet 1P/Halley has ejected over the eons.

Martin Ratcliffe provides profes-
sional planetarium development
for Sky-Skan Inc. in Nashua, New
Hampshire. Meteorologist **Alister
Ling** works for Environment
Canada in Edmonton, Alberta.

Rising Moon

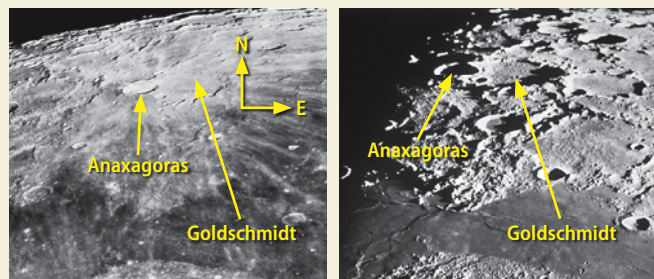
A northern crater makes a big splash

The Moon's north polar region changes appearance throughout the lunar month. In scenes reminiscent of seasonal changes near Earth's poles, the lunar north transforms from highly reflective to cratered shadows and back again. At April's close, the high Sun at Full Moon blankets the region with gray patches and white rays that converge toward the youthful crater Anaxagoras.

Use a filter to cut down on glare, and you'll see that bright material ejected during Anaxagoras' formation blankets this crater's older neighbor Goldschmidt. Anaxagoras formed around the same time as Tycho, and it likely would be just as famous if it weren't in the far north and foreshortened so much.

In early May, a widespread zone of craters appears as lunar sunset progresses. Return to the area May 21, when the rising Sun brings sharp-rimmed Anaxagoras back into the light. The crater's deep bowl remains in shadow for another day.

Notice how Anaxagoras carves into the edge of the sprawling and shallow Goldschmidt. The lower rim of the older crater still man-
ages to cast decent shadows across its freckled floor. As Full Moon



The young crater Anaxagoras breaks the rim of ancient Goldschmidt. Bright ejecta from Anaxagoras appears conspicuous near Full Moon (left) but not later in the lunar month (right). Consolidated Lunar Atlas/UJA/LPL

approaches after May 25, watch Anaxagoras turn into the north's brightest splotch of rays.

You can get the feeling you're in low lunar orbit by pumping up the power on the north limb around Full Moon. Each bump casts a shadow northward, creating impressive 3-D views. This month, the perspective peaks from May 26 to 28.

When to view the planets

EVENING SKY

Venus (west)
Mars (southwest)
Saturn (south)

MIDNIGHT

Mars (west)
Saturn (southwest)

MORNING SKY

Mercury (east)
Jupiter (east)
Uranus (east)

rings bisecting a nearly complete disk. The rings tip just 1.7° to our line of sight in the second half of May, their minimum tilt during 2010. This tilt will double by early August, and it will double again by October. By the end of the year, the rings will tilt an impressive 10°. Any small telescope will let you follow their gradual opening.

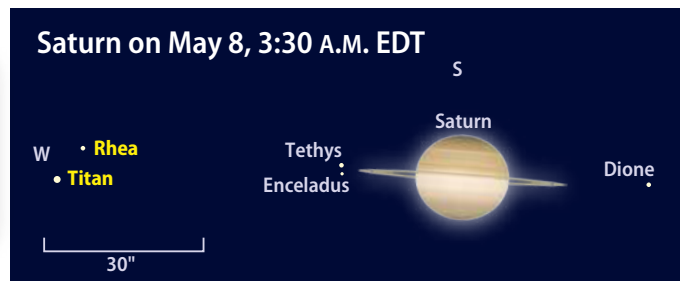
With Saturn's globe displayed nicely, take a minute to note its non-circular appearance. The disk spans 18.6" across the equator and 16.8" through the poles, a 10 percent difference and the largest flattening of any planet in our solar system.

Now is also a good time to look for features in Saturn's

atmosphere. They remain subtle, far more so than those on Jupiter, so patience at the eyepiece is key. The most obvious features are a relatively dark equatorial belt and the dark polar hood. White spots appear occasionally. Saturn's rapid rotation carries any such spot across the planet's disk in just 5 hours.

The bright dot you'll see near Saturn is its brightest moon, Titan. This world has a nitrogen-rich atmosphere thicker than Earth's and lakes of liquid methane on its surface. You won't see any of that through a telescope, of course; Titan shows up as an 8th-magnitude speck that changes position from night to night.

Titan circles Saturn in nearly the same plane as the



Saturn's moons Titan and Rhea approach within 6" of each other May 8. The two lie well west of the planet while a couple of fainter moons hover near the ringed world. *Astronomy: Roen Kelly*

rings, and the current low tilt means the moon passes in front of and behind the planet once each orbit. Viewers in North America can watch the first such event the morning of May 1, when Titan approaches Saturn. The moon passes in front of the planet (a transit) starting around 4:25 A.M. EDT. The transit lasts about 4 hours, concluding after Saturn sets across most of the continent.

You will need a 10-inch or larger telescope to see Titan as a peach-colored dot against Saturn's cloud tops. Titan's second transit of the month starts

at about 2:20 A.M. EDT May 17 and lasts until 6:50 A.M.

Titan also passes behind Saturn twice in May. The planet occults the moon May 9 beginning at 5:50 A.M. EDT. Titan disappears again May 25 at around 3:55 A.M. EDT. Observers in western North America will have the best views as Titan disappears at the start of both occultations.

Saturn's second-brightest moon, Rhea, passes a mere 6" south of Titan the morning of May 8. The two appear near each other all morning, but only those west of the Mississippi River can see closest

Comet search

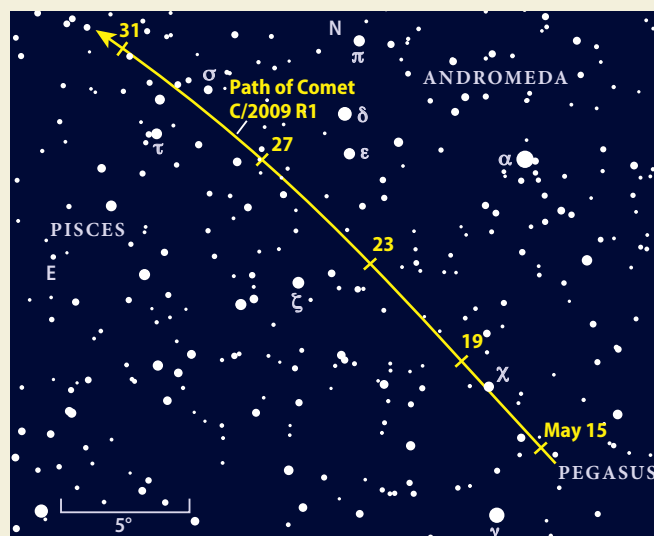
May delivers a trio of temptations

May should be a great month for comet observers. Three visitors glow at 10th magnitude or brighter, and two of them remain visible most of the night. Good viewing opportunities for 10th-magnitude C/2009 K5 (McNaught) open in late April. On Saturday night, April 24/25, it passes between the 8th-magnitude open cluster NGC 6939 and the 9th-magnitude galaxy NGC 6946. The best views will come after the Moon sets around 4 A.M. local daylight time. Astroimagers should mark this event on their calendars.

The comet has more nice conjunctions in May. It passes near the 2nd-magnitude star Polaris during the month's second half. And, on the New Moon weekend of May 14 and 15, C/2009 K5 lies just 3° from the open star cluster NGC 188. This ancient group of stars lies less than 5° south of Polaris.

Another 10th-magnitude comet worth visiting is 81P/Wild. This periodic comet lies in Virgo, where it spends the entire month less than 3° west of 4th-magnitude Iota (ι) Virginis. Comet Wild also has a deep-sky companion: globular cluster NGC 5634. The cluster lies some 5° east of the comet, and the two should look similar in size, brightness, and appearance.

May's brightest comet lurks in the eastern sky before dawn. Comet C/2009 R1, another object discovered by Australian astronomer Robert McNaught, should glow at 8th magnitude. You can find it crossing the southeastern corner of the Great Square of Pegasus.



Comet C/2009 R1 (McNaught) brightens to 8th magnitude this month as it makes its way from Pegasus into Andromeda. *Astronomy: Roen Kelly*

If the comet continues to brighten as predicted, it will crest at 5th magnitude in June, when sharp-eyed observers under dark skies might glimpse it with their naked eyes.

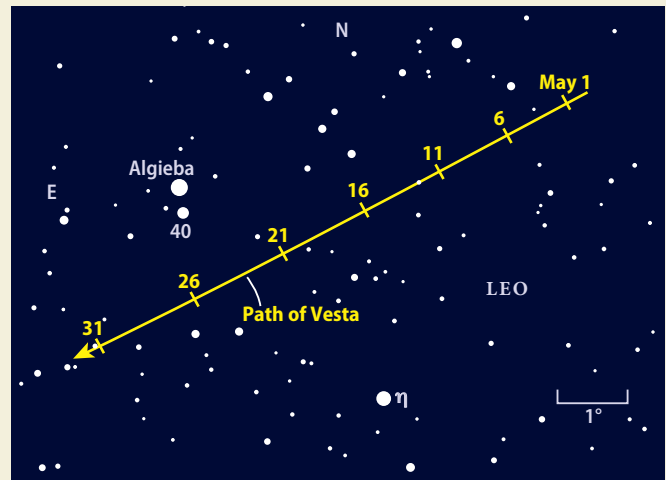
Locating asteroids

Vesta seeks to decapitate the Lion

Soaring high in the southwest at dusk, asteroid 4 Vesta pierces the neck of Leo the Lion during May. Vesta glows around magnitude 7.5, so it remains well within reach through a small telescope from the suburbs. It's an easy star-hop north of 1st-magnitude Regulus, but it lies even closer to 2nd-magnitude Algieba (Gamma [γ] Leonis). Algieba stands halfway up the Sickle asterism that forms Leo's head.

Vesta reached the end of its retrograde loop in April, and its eastward motion quickens in May. You can follow the night-to-night displacement of this 320-mile-wide rock with ease. Using low power, sketch 4 or 5 stars that surround Vesta. Then return to the same region a night or two later and see which dot has changed position.

Astronomers and backyard observers alike eagerly await the arrival of NASA's Dawn spacecraft at Vesta in August 2011. We'll discover why Vesta is one of the shiniest asteroids, reflecting more sunlight than all but a handful of others. It has been 10 years since the NEAR-Shoemaker spacecraft orbited the Earth-approaching asteroid 433 Eros and returned stunning close-up photos. We should expect no less from the coming Dawn.



Vesta glides east through Leo the Lion's head during May, passing less than 2° south of the 2nd-magnitude double star Algieba late in the month. *Astronomy: Roen Kelly*

approach, which comes shortly before Saturn sets. Rhea glows 1.3 magnitudes fainter than Titan and shows up in a 3-inch scope.

Saturn's outermost major moon, Iapetus, reaches greatest western elongation the night of May 6/7. At this orbital location, Iapetus' bright hemisphere faces Earth. The moon then glows at 10th magnitude and shows up through most telescopes. It takes nearly 3 weeks for Iapetus to swing back toward Saturn. The moon stands 1.3' north of the planet May 27, when Iapetus already has faded to 11th magnitude.

As Saturn dips toward the western horizon, you can start to hunt for **Neptune** in the east. The outer planet rises a little after 2 A.M. local daylight time in mid-May and stands 20° high as twilight begins. It glows at magnitude 7.9, bright enough that binoculars will bring it into view.

Neptune currently lies in western Aquarius, less than 1° from where Johann Galle discovered it September 23, 1846. Look for the planet about halfway between Mu

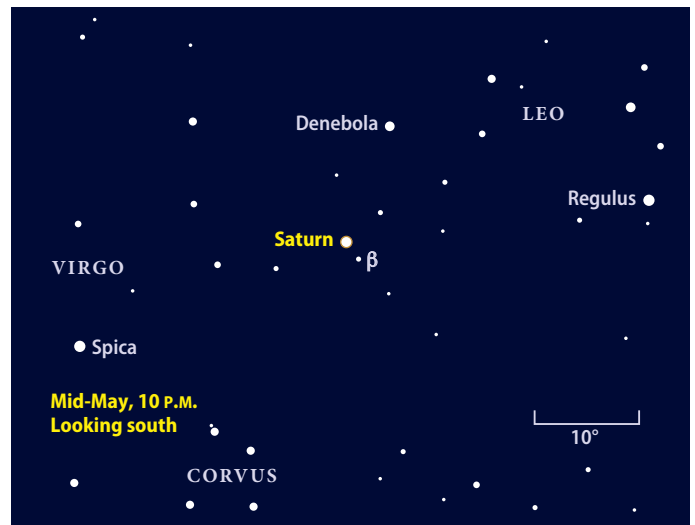
(μ) Capricorni and 38 Aquarii, a pair of 5th-magnitude stars that straddle the border between Capricornus and Aquarius.

About an hour after Neptune rises, **Jupiter** pokes above the eastern horizon. You won't need any help identifying Jupiter, however — it's the brightest point of light in the predawn sky. The giant planet shines at magnitude -2.2 and dominates the heavens until twilight overwhelms all the stars.

When viewed through a telescope, Jupiter's disk spans $36''$ across the equator. Count yourself lucky if you can make out details in the planet's cloud tops. Turbulence in our own atmosphere blurs fine features on any celestial object near the horizon.

Turbulence won't mask Jupiter's four large moons, however. Io, Europa, Ganymede, and Callisto appear as bright dots arrayed on either side of the planet's disk. Viewing conditions for Jupiter will improve markedly by late June.

Uranus lies in the same binocular field as Jupiter. The two begin May nearly 5° apart



The ringed planet moves slowly against the background stars of Virgo, staying near 4th-magnitude Beta (β) Virginis. Saturn's brightness nearly matches that of the Maiden's brightest star, Spica. *Astronomy: Roen Kelly*

(with Uranus to the northeast), but the gap narrows to 1° by month's end. Binoculars easily reveal Uranus, which glows at magnitude 5.9. But you'll need a telescope to see its $3.4''$ -diameter blue-green disk. As with Jupiter, views of Uranus will grow much better this summer.

You'll have to search the bright morning twilight to glimpse **Mercury**. The innermost planet reaches greatest western elongation May 25/26,

when it stands 25° from the Sun. Most of this angular separation parallels the eastern horizon, however, so Mercury does not climb high.

At greatest elongation, Mercury lies just 5° above the eastern horizon 30 minutes before sunrise. It then glows at magnitude 0.4 and appears as a bright point when you scan the twilight sky with binoculars. A telescope shows a disk $8''$ in diameter and just 39 percent lit. ☿

Galaxies near the dawn of time

The Hubble Space Telescope's latest and greatest deep-field image uncovers a population of compact and ultra-blue galaxies more than 13 billion light-years from Earth. **by Richard Talcott**

Twenty years after space shuttle astronauts deployed the Hubble Space Telescope, the orbiting observatory continues to reach new heights. Now, astronomers have used Hubble's Wide Field Camera 3 (WFC3) to scale a fresh peak — by plumbing uncharted depths. The newly installed camera peered deeper into the universe than Hubble ever had before and revealed galaxies more than 13 billion light-years from Earth.

Richard Talcott is a senior editor of *Astronomy* and author of *Teach Yourself Visually Astronomy* (Wiley Publishing, 2008).

These galaxies also give us a look far back in time. The most distant galaxies in the new images existed just 600 million years after the Big Bang. These objects are much smaller than the Milky Way and other big galaxies that dominate the universe today. In effect, they give researchers a look at the baby galaxies that ultimately grew into the mature objects surrounding us.

The latest results come from two sets of Hubble observations. The first targeted a pencil-thin slice of sky in the northeastern corner of the southern constellation Fornax. Astronomer Garth Illingworth of the University of California, Santa Cruz, led the team that pointed WFC3 at the spot for 48 hours. The camera



Thirteen billion years of cosmic history show up in this panoramic view taken by the Hubble Space Telescope. The scene contains thousands of galaxies from the nearby universe to more than 13 billion light-years away — the most distant objects astronomers have ever seen. The image combines photos taken through 10 filters from ultraviolet through visible light and into the near-infrared. NASA/ESA

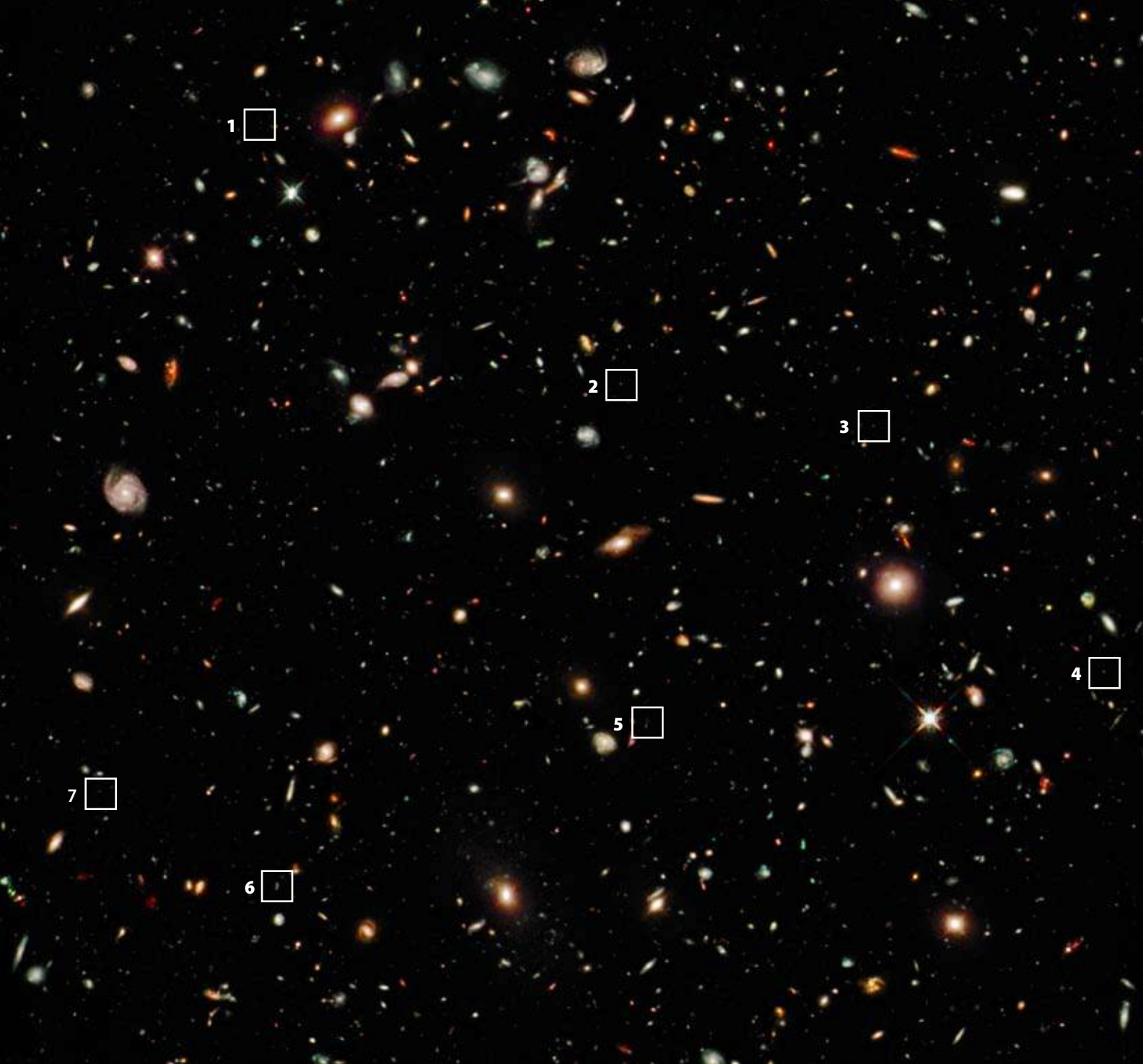
took images through three filters that isolate different wavelengths in the near-infrared part of the spectrum.

This region coincides with the original Hubble Ultra Deep Field (HUDF), taken in visible light by the Advanced Camera for Surveys (ACS) in late 2003 and early 2004. Many of the discoveries from the new HUDF09 come through comparing it with the original Ultra Deep Field.

A second team, led by Rogier Windhorst of Arizona State University, observed a slightly larger area just north of the HUDF09. For this panoramic photo, the team combined WFC3 observations at three near-infrared wavelengths and

three ultraviolet wavelengths with earlier ACS images through four visible-light filters. The resulting 10-color mosaic provides an unprecedented view of thousands of galaxies.

Both fields lie within a wider region targeted by the Great Observatories Origins Deep Survey (GOODS), an extragalactic laboratory for studying cosmic evolution. Astronomers have viewed this area with Hubble, the infrared-sensitive Spitzer Space Telescope, the Chandra X-ray Observatory, and large ground-based telescopes. The region appears nearly empty without a big telescope — the brightest star glows at 14th magnitude, some 1,000 times dimmer than the faintest naked-eye star.



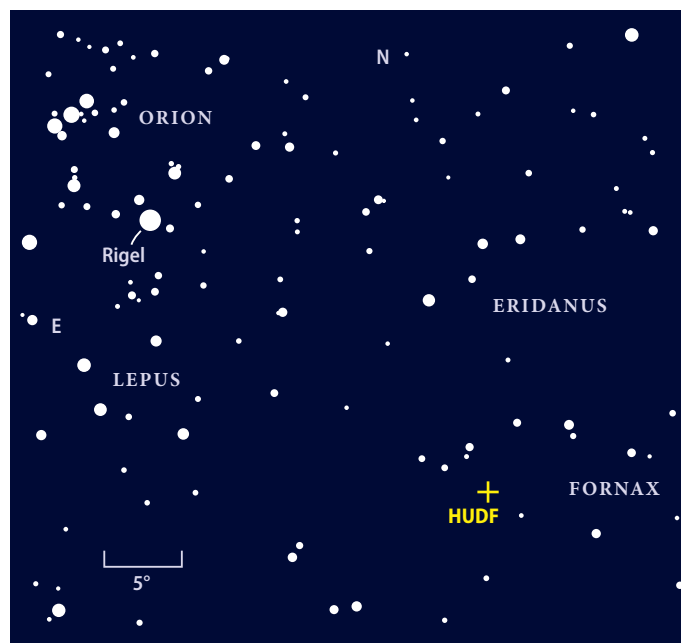
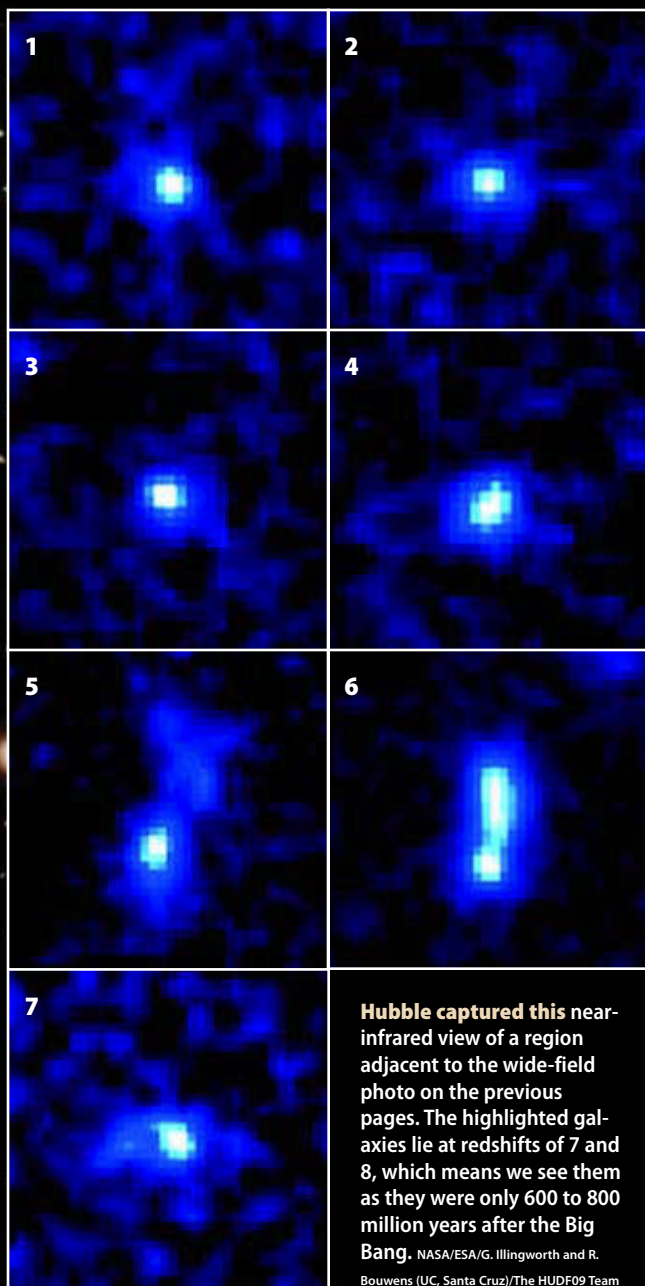
Hunting the cosmic edge

Within weeks of Hubble's observations, astronomers discovered a slew of distant galaxies in the fields. Finding these far-flung objects isn't as easy as you might expect. For brighter and nearer galaxies, the task is pretty simple: Take a spectrum of the object through a large scope, and determine its redshift. The redshift measures how much the universe's expansion has shifted the light to longer (redder) wavelengths.

Not only are the new galaxies exceedingly faint, but they also lie so far away that their light has been shifted out of the visible spectrum. No telescope on Earth or in space can capture a spec-

trum of the farthest galaxies. Instead, astronomers determine their redshifts, and thus distances, from how bright they appear through different near-infrared filters. (See "How to find a galaxy's distance" on page 61.) That's where WFC3 comes in. Only it has the capability to see the faint light from these remote galaxies.

Illingworth's team, one of six exploring the new data, discovered 16 galaxies at redshifts of around 7 and five more at redshifts of 8. The farthest one has a redshift of about 8.5, which corresponds to an era just 600 million years after the Big Bang. (See "Age vs. redshift" on page 59 for the relationship between the two.) And this comes just 6 years after Hubble's ACS set the



The Hubble Ultra Deep Field lies in a nondescript part of the southern constellation Fornax. At the scale of this map, the field is far smaller than the size of the cross. *Astronomy: Roen Kelly*

Age vs. redshift

A galaxy's redshift is a measure of how far away it lies, and thus how long after the Big Bang its light left. A redshift of 0 means the light hasn't shifted at all, so it represents the current universe. A redshift of 1 means the light has shifted by 100 percent, so the wavelengths are twice as long; a redshift of 2 means the wavelengths are 3 times as long. The most distant confirmed galaxies in the Ultra Deep Field have redshifts between 8 and 9, so we see them as they were only 600 million years after the Big Bang. — *R. T.*

Redshift	millions of years since the Big Bang
0	13,700
0.5	8,700
1	5,900
2	3,300
3	2,200
4	1,600
5	1,200
6	950
7	780
8	650
9	560
10	480

previous record by uncovering galaxies at redshifts slightly greater than 6, some 900 million years after the Big Bang.

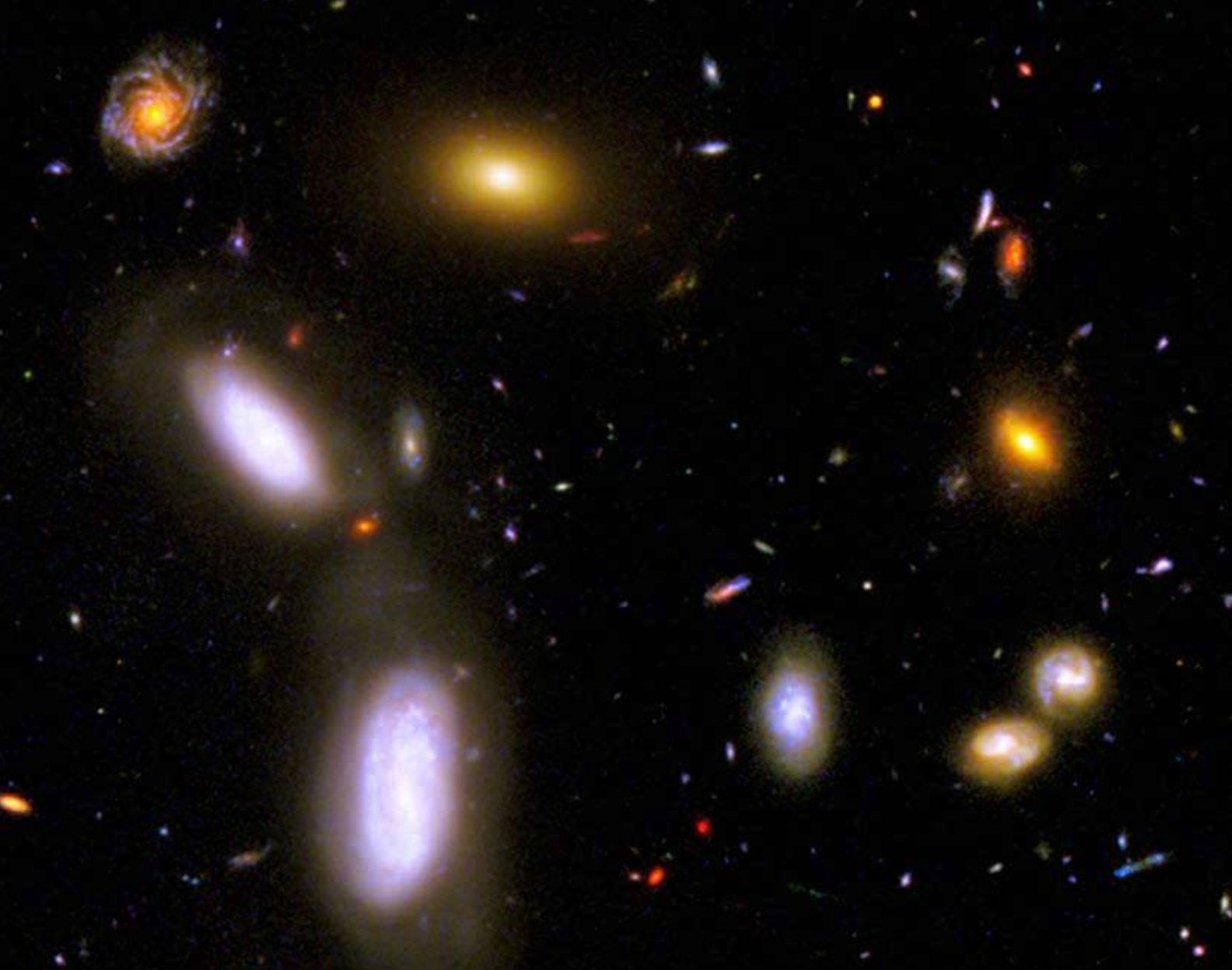
Illingworth even claims evidence for three galaxies at redshifts of about 10, which pushes their ages back to within 500 million years of cosmic genesis. These galaxies show up through only the longest-wavelength WFC3 filter, however, so the team isn't quite as confident in these detections.

Small and blue

The newfound galaxies don't bear much resemblance to the majestic spirals and great ellipticals prominent in the nearby

universe. They have diameters only about 5 percent that of the Milky Way and masses less than 1 percent that of our galaxy. Still, Hubble reveals them as more than mere dots. Several appear ragged and distorted, no doubt through encounters with their neighbors. These baby galaxies are the seeds that grow through mergers into large galaxies like ours.

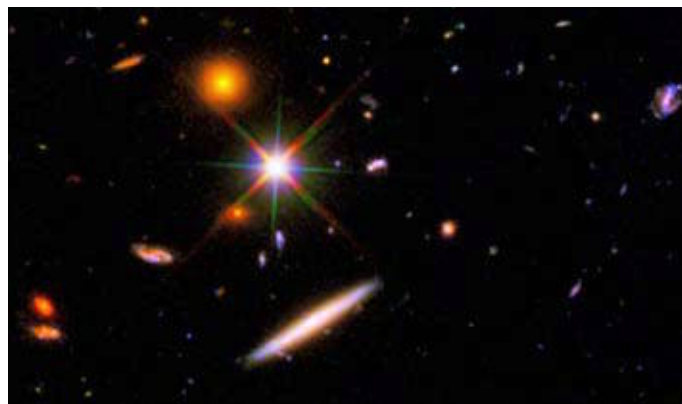
These distant objects also are much bluer than galaxies today. (Don't get confused by this color reference; they still *appear* red to our telescopes. But when scientists factor out the redshift caused by universal expansion, they realize these galaxies emit light at the blue end of the spectrum.)



Two apparently interacting galaxies dominate the left side of this close-up from Hubble's panoramic deep field (at the bottom center of the image on pages 56 and 57). These two have redshifts of 0.08, which means they lie just 1 billion light-years from Earth. The pretty face-on spiral galaxy at top left has a redshift of 0.68, which places it more than 6 billion light-years away. The faintest galaxies here are more than 10 billion light-years distant. NASA/ESA



The large ring-shaped spiral galaxy at the bottom of this detailed close-up image lies 1.3 billion light-years from Earth. It has a redshift of 0.1, which means cosmic expansion has shifted the light it emits 10 percent toward the red end of the spectrum. NASA/ESA



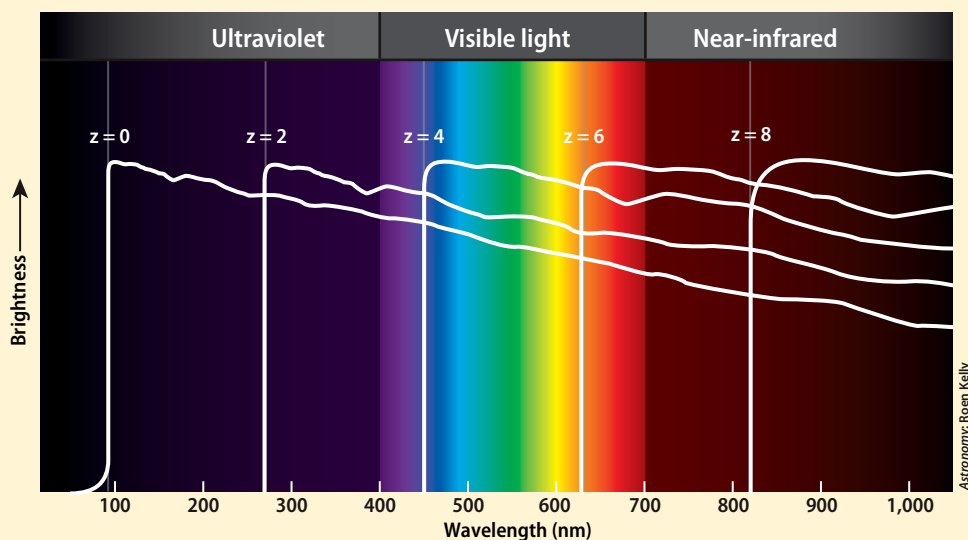
Spying distant galaxies in the Hubble Ultra Deep Field involves finding faint red objects that appear as more than points of light. The bright object just left of center with spikes coming from it is a star in our own galaxy, one of only a handful in this tiny region of sky. NASA/ESA

How to find a galaxy's distance

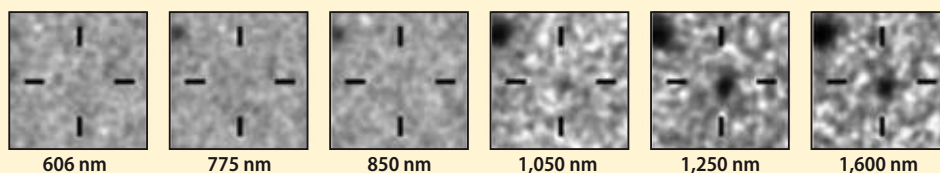
To gauge how far away a distant galaxy is, astronomers need to measure its redshift. Cosmic expansion shifts the light of any object to longer wavelengths, and the farther away it lies, the more the light is redshifted. Usually, an object's spectrum will give you its redshift. Unfortunately, the most distant galaxies are too faint and too red for any telescope to get a spectrum.

But nature provides an alternative. Neutral hydrogen in a galaxy absorbs almost all light with wavelengths shorter than 91.2 nanometers. So, a galaxy's spectrum has a sharp break at that wavelength. For more-distant objects, cosmic expansion causes the break to shift to longer wavelengths.

If astronomers take images of the sky through different filters, a distant object will show up at longer wavelengths and not at shorter ones. The wavelength at which the object disappears, or "drops out," gives an estimate of the redshift. This drop-out technique gives results accurate to about 4 percent. — R. T.



The most distant galaxies show up only at near-infrared wavelengths because the light they emit gets redshifted beyond the visible. This graphic shows the effect of redshift on a typical galaxy's light.



A distant galaxy leaps out of the background when viewed at near-infrared wavelengths. This newly discovered galaxy, at a redshift of 8.4, does not appear to Hubble's Advanced Camera for Surveys (the three wavelengths at left) but comes into view at the near-infrared wavelengths the Wide Field Camera 3 can record (the three wavelengths at right). NASA/ESA/G. Illingworth (UC, Santa Cruz)

Astronomers interpret this blueness to mean that the galaxies contain significantly less dust than closer galaxies and few heavy elements. Heavy elements build up in stars over time. Supernova explosions then disperse those elements, which form dust, and the dust scatters and reddens starlight.

"The faintest galaxies are so blue that they are likely to be quite deficient in heavy elements, and thus represent a population that has nearly primordial characteristics," says Illingworth's colleague Rychard Bouwens of the University of California, Santa Cruz. Although they may have some primordial characteristics, these are not primordial galaxies. Combining the new Hubble observations with those made by Spitzer at longer wavelengths shows that galaxies at redshifts of 8 must have been making stars about 300 million years earlier — just 300 million years after the Big Bang.

Into the Dark Ages

These early galaxies lie well within the universe's so-called Dark Ages. This era began some 380,000 years after the Big Bang, once the universe had cooled enough for electrons to combine with protons. The resulting hydrogen atoms allowed light to travel unimpeded for the first time, and the cosmic background radiation started to permeate the cosmos.

Eventually, sometime between 400 and 900 million years after the Big Bang, the young universe generated enough radiation to reionize the hydrogen. But nobody knows for sure what objects contributed to it. Most astronomers think young galaxies did much of the heavy lifting. However, galaxy counts of the youthful cosmos show that they may not have produced the radiation alone. Other scientists suspect mini-quasars fueled by supermassive black holes could have done the trick, or at least helped.

Astronomers hope to glean further clues from additional observations in the GOODS region. The HUDF09 data used to date covers only about one-third of the area researchers plan to observe. Hubble went back and viewed more in February and will wrap up the imaging later in 2010. But it likely will take the James Webb Space Telescope to make real headway. This 6.5-meter telescope, due to launch in 2014, is optimized to observe infrared radiation and take spectra of faint objects.

"This is about as far as we can go to do detailed science with the new HUDF09 image," says Illingworth. "This shows just how much the Webb Telescope is needed to unearth the secrets of the first galaxies." ☛



To learn about the Hubble Space Telescope's earlier deep fields, visit www.Astronomy.com/toc.

Creating heavy elements

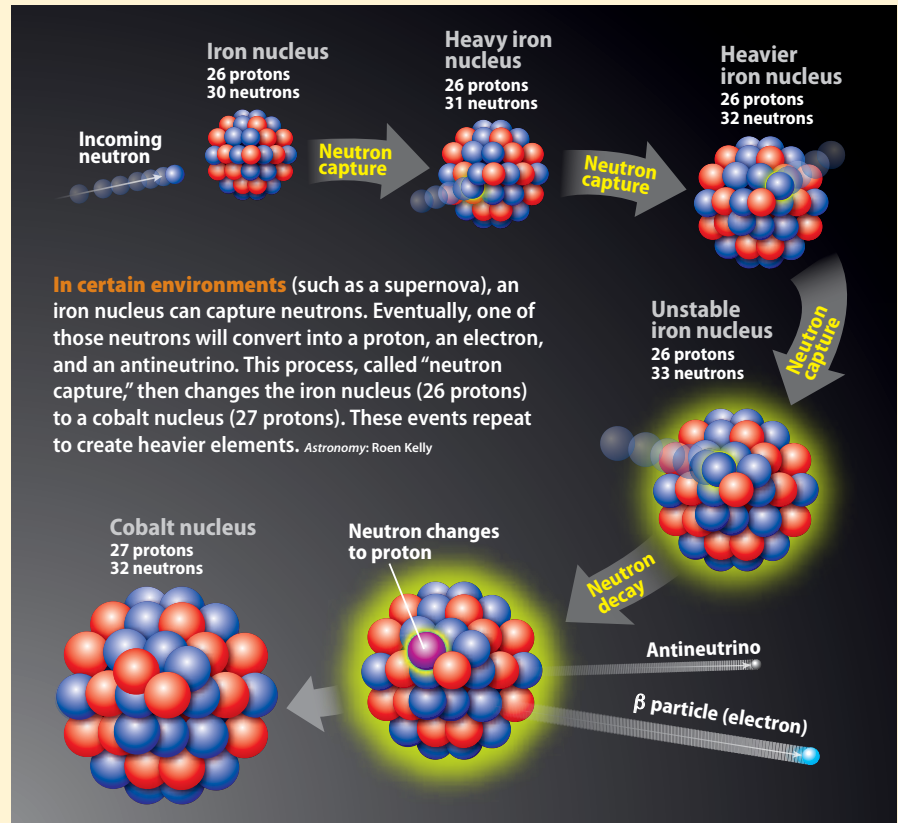
Q: My astronomy book reads, "Heavy-element fusion in massive stars ends with iron." How are elements heavier than iron in the periodic table created?

— Kate Jenks, Lexington, Virginia

A: Great observation! Iron is the most tightly bound nucleus. You can't just add a proton to the nucleus to create a heavier atom because the positive charge of the protons in the nucleus repels the positive charge of any protons you try to add. But elements heavier than iron exist in nature, so there must be a way to create them.

In an environment packed with excess energy (like a supernova), a small fraction of this energy may be used to bind free neutrons to iron atoms. Because a neutron has no charge, unlike a proton, it doesn't experience a repulsive force from the nucleus. This event increases only the mass of the nucleus, not the charge.

If too many neutrons compared to the number of protons accumulate in the nucleus, the nucleus becomes unstable. **One of the neutrons in the nucleus decays (or changes) into a proton, and the nucleus's**



charge increases by one to produce a heavier element.

Astronomers call this sequence of events a "neutron capture" process. You

can imagine repeating this process over and over again to produce the heavy elements found in the universe.

— Ian U. Roederer, University of Texas, Austin

BEGINNING ASTRONOMY

Q: What is the number one piece of advice a beginning astronomer needs to receive? — Kyle Norris, Peoria, Arizona

A: I have two "number one" pieces of advice. **First, find a mentor — someone well-versed in astronomy who can provide useful guidance.**

If you're not fortunate enough to know an experienced observer, try an astronomy club. Contact the club to see if a member lives near you and would be willing to mentor you. You'll find a list of astronomy clubs at www.Astronomy.com.

No astro-savvy friends or local astronomy clubs? If you have to go it alone, become acquainted with the night sky. Start by using *Astronomy's* monthly star chart outside to teach yourself the location and identity of the major stars and constellations visible that month — a critical skill if you want to explore the night sky with optical aid.

My second tip is to start out slow. Whether you work with a mentor or go it alone, don't immediately buy a \$5,000 telescope/astrophotography setup. After you become familiar with the major stars and constellations and want to move up

from naked-eye astronomy, look for good binoculars — preferably the 7x50 or 10x50 size. An essential tool for any serious amateur astronomer, binoculars bridge the gap between the naked eyes and a telescope.

When you feel ready for a telescope, purchase something simple and easy to handle. My preference is a 6- or 8-inch Dobsonian-mounted reflector. It's relatively inexpensive and user friendly. A



Visit www.Astronomy.com/toc to find out if our solar system's plane aligns with the Milky Way's.

scope like this will last for years and reveal hundreds of cosmic wonders, from craters on the Moon to distant galaxies. If a few years pass and you still have astronomy fever, go ahead and get that \$5,000 high-tech telescope/astrophotography setup. — **Glenn Chaple**, Contributing Editor

GRAVITATIONAL DISTORTIONS

Q: How are we sure that images classified as gravitational lensing are a distortion of light, not existing objects? — **Alexandros Vorrias**, Chios, Greece

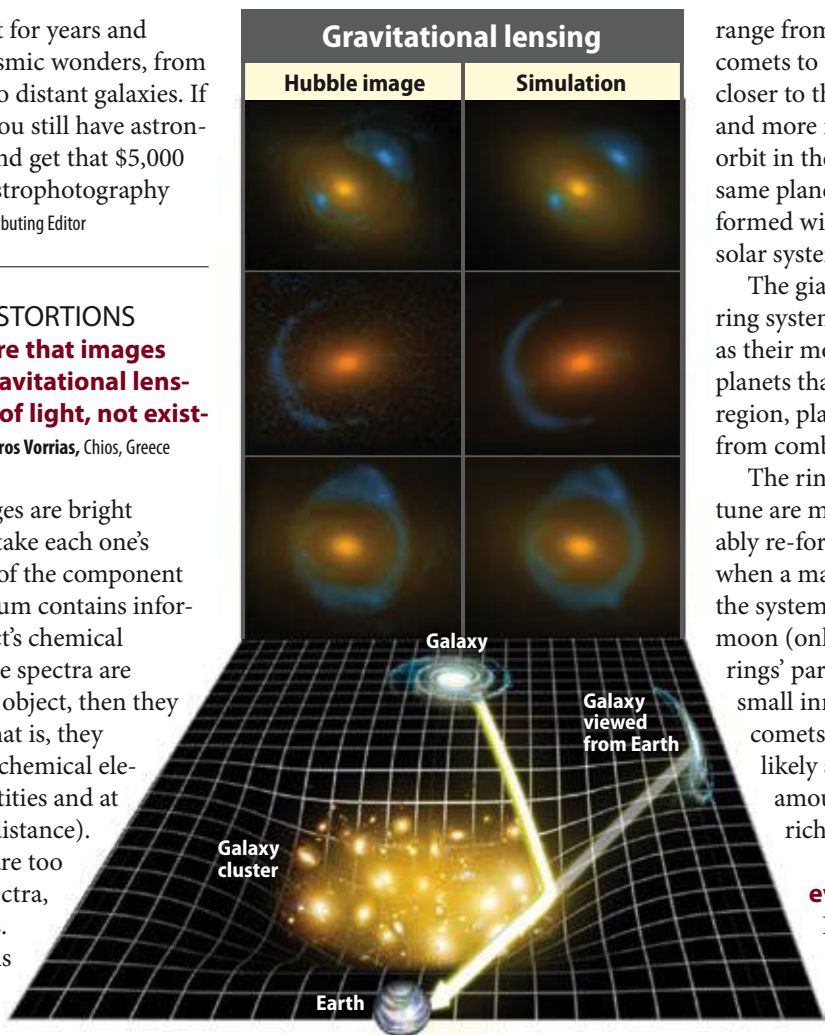
A: When such images are bright enough, we can take each one's spectrum — a profile of the component wavelengths. A spectrum contains information about an object's chemical makeup. If the separate spectra are indeed from the same object, then they should be identical (that is, they should have the same chemical elements in similar quantities and at the same redshift, or distance).

When the images are too faint for us to take spectra, we look at their colors. Gravitational lensing is an achromatic effect, so multiple images of a source should have the same color as the source. A large percentage of "gravitational lens candidates" do not

survive the tests noted above. For those that do, we still cannot conclude they are images of the same object.

Multiple-image candidates can be, for example, binary systems. Perhaps the binaries are exchanging material; hence they can potentially have similar composition. **To definitively conclude the lens nature of an image, we should identify the lens (a galaxy and/or a galaxy cluster) and model its mass distribution using what researchers know about galaxy and galaxy cluster physics.**

If by doing so we can reproduce the shape of the images, their relative positions, and magnifications, then we can be quite certain that we are looking at a genuine gravitational lens. — **Cécile Faure**, Ecole Polytechnique Fédérale de Lausanne, Switzerland



To verify that multiple images are one object that's been gravitationally lensed, astronomers model the foreground lens object and the background object. The Sloan Lens ACS Survey (SLACS) survey imaged gravitational lens candidates with the Hubble Space Telescope (left panels) and compared them to computational models (right panels). The illustration shows how a massive object lenses light from a galaxy. A. Bolton, for the SLACS team and NASA/ESA; Astronomy: Roen Kelly

NOT-SO-BLING RINGS

Q: Why didn't any of the other gas giants (Jupiter, Uranus, or Neptune) develop a large ring system like Saturn? — **Aykut Altug**, Los Angeles

A: Our outer solar system's giant planets divide into two categories. Jupiter and Saturn are the "gas giants" — primarily a mix of hydrogen and helium, with some tens of percent rocky and icy material that reside in a dense core in Saturn but may be more spread throughout Jupiter's interior. The "ice giants" Uranus and Neptune have fairly thin shells of hydrogen-helium atmospheres surrounding massive cores — 20 to 30 Earth masses of a rock-ice mix.

All four giant planets have regular satellite systems containing moons that

range from the size of small asteroids or comets to Earth's Moon. The moons closer to the planet tend to be smaller and more numerous. All inner moons orbit in the same direction and in the same plane. These moons probably formed with their parent planets at the solar system's beginning.

The giant planets also have their own ring systems, which lay in the same plane as their moons but closer to the parent planets than the satellites. In the rings' region, planetary tides disrupt rubble from combining into moons.

The rings of Jupiter, Uranus, and Neptune are mere wisps of debris. They probably re-form every million years or less when a marauding comet flies through the system and destroys a small nearby moon (only a few miles across). The rings' particles are fairly dark, like the small inner moons of these planets, comets, and asteroids. They are all likely a mixture of roughly equal amounts of ice, rock, and carbon-rich organics.

Saturn's ring system, however, is unusual in two ways:

It is by far the most massive, and its particles are mostly pure water ice. Its parent must have been a large moon, like Mimas, that melted and separated its ices from its rocks. Impactors large enough to destroy such a massive parent are rare and likely

haven't happened in the geologically recent past. But if the rings are old, why hasn't the constant infall of much smaller interplanetary debris "polluted" the ring particles to a much darker appearance than we see? (Astronomers know that less than 10 percent of Saturn's ring mass is rocky material.)

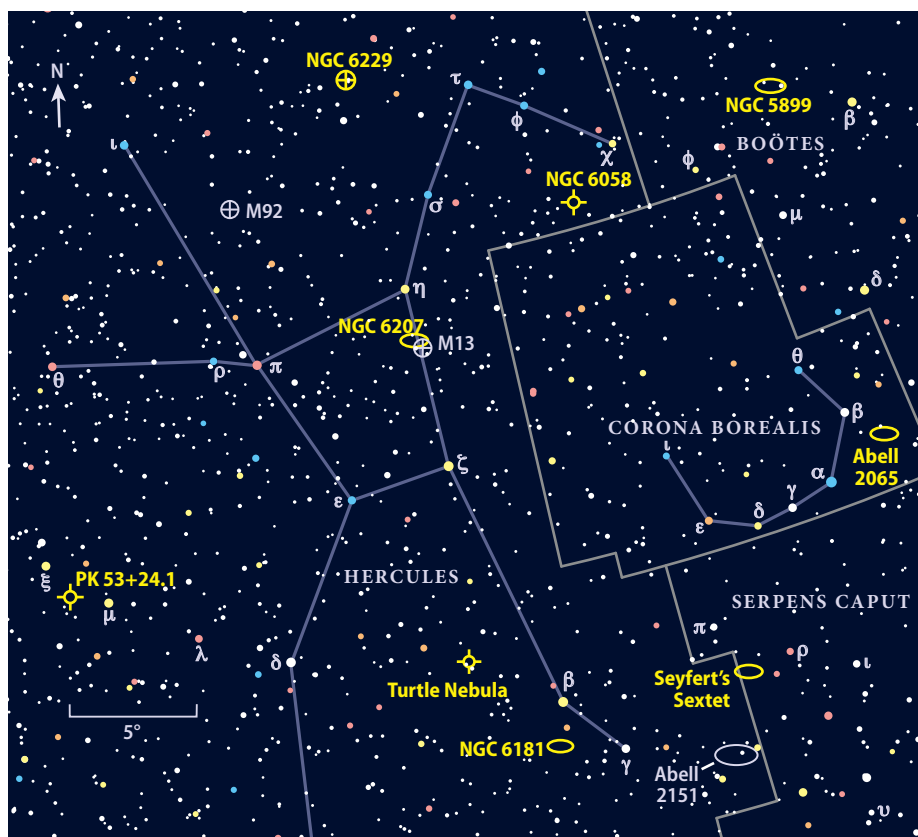
So the mystery is not why the other three planets didn't develop large, bright, icy ring systems, but why Saturn did! — **Jeff Cuzzi**, NASA's Ames Research Center, Mountain View, California

Send your questions via e-mail to: askastro@astronomy.com; or write to **Ask Astro, P.O. Box 1612, Waukesha, WI, 53187**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Target **30** obscure celestial gems

This list of faint, fainter, and faintest deep-sky targets will take your observing skills to the next level. **by Michael E. Bakich**

Some terrific celestial objects shine in the summer sky. Among them are the Lagoon Nebula (M8), the Hercules Cluster (M13), and the Ring Nebula (M57). And while amateur astronomers proudly show off these wonders at public events, you may be yearning privately for slightly more challenging fare. In that spirit, I present this list.



Hercules the Hero dominates this region of sky, but you'll also find great deep-sky targets in Boötes, Corona Borealis, and Serpens. *Astronomy: Richard Talcott and Roen Kelly*

A heroic start

The first part of our obscure object hunt centers on Hercules. This star pattern covers nearly 3 percent of the sky. Hercules' most easily recognized feature is the Keystone asterism, made of the stars Eta (η), Pi (π), Epsilon (ϵ), and Zeta (ζ).

That said, our first object, spiral galaxy **NGC 5899**, lies in Boötes. You'll find this object, and three other galaxies, 3° northeast of magnitude 3.5 Nekkar (Beta [β] Boötis). The orange magnitude 6.1 star SAO 45445 lies 0.2° to the northwest of NGC 5899. Through an 8-inch scope, you'll see a magnitude 11.8 disk-shaped object more than twice as long as it is wide oriented north-northeast to south-southwest. The galaxy's northern half glows brighter than the southern portion.

Through at least a 14-inch scope from a dark site, you can search for a trio of faint galaxies near NGC 5899. Look $9'$ north for magnitude 14.1 NGC 5900. Magnitude 14.3 NGC 5895 lies $14'$ west-southwest, and magnitude 13.2 NGC 5893 sits $4'$ southwest of NGC 5895.

Now head to Corona Borealis, look 2° southwest of Nusukan (Beta Coronae Borealis), and target galaxy cluster **Abell 2065**. This fine object is a challenge even through a 16-inch scope. Within the half-degree field that encompasses this cluster, you'll see half a dozen galaxies.

On a recent trip to Rancho Hidalgo Astronomy Village in New Mexico, I observed this object through a 30-inch scope under a pristine sky. I judged the sighting moderately difficult because the individual members appear faint. And well they should! This cluster lies 1 billion light-years from Earth.

Our next celestial treat is a group of six galaxies — three faint and three ultra-faint — that occupy a tiny area of sky in

Seyfert's Sextet in Serpens ranks as a challenging observation for amateur astronomers. The brightest galaxy glows at magnitude 13.4.

Don Goldman





▲ **Globular cluster NGC 6229** in Hercules lies near two much closer stars that accompany it across the sky. *Martin C. Germano*



▲ **Abell 2065** is a galaxy cluster in Coma Berenices. Through the largest amateur instruments, you'll see two dozen faint galaxies. *Tony Hallas*

< **Spiral galaxy NGC 6207** lies near the Hercules Cluster, albeit 1,600 times as far away. NGC 6207 measures 3' by 1.1'. *Dietmar Hager*



Serpens. **Seyfert's Sextet** is made up of magnitude 13.8 NGC 6027, magnitude 13.9 NGC 6027a, magnitude 13.4 NGC 6027b, magnitude 16.5 NGC 6027c, magnitude 16.5 NGC 6027d, and magnitude 15.5 NGC 6027e.

Look for Seyfert's Sextet 1.9° east of magnitude 4.7 Rho (ρ) Serpentis. Even through a 16-inch telescope, at magnifications below 200x it's easy to mistake this group for a single object. None of the galaxies shows any real structure, and each appears nearly stellar through any size scope. Merely detecting all six members ranks as a major accomplishment.

Our next target lies 2.8° southeast of magnitude 4.6 Chi (χ) Herculis. Through small telescopes, you'll see the triangle of stars that surrounds **NGC 6058** before you see the planetary nebula itself.

Through an 8-inch scope, the planetary appears evenly illuminated. The tiny central region looks a bit brighter. A 14-inch instrument will reveal a small halo surrounding the 13th-magnitude central star. A nebula filter helps a lot.

Look for the next object on our list 1.7° south-southeast of magnitude 2.8 Kornephoros (Beta Herculis). Spiral galaxy **NGC 6181** glows softly at magnitude 11.9 and lies twice as far away as the galaxies in the Virgo cluster.

Through a 10-inch scope, you'll see the 2'-long oval halo oriented north-south. The core is broad and evenly lit.

Through a 16-inch scope, you may glimpse the thin spiral arms that appear at the northern and southern ends. The north arm curves westward and the southern arm eastward.

Although our next target glows meekly at magnitude 11.6, it's easy to locate. First, find the magnificent Hercules Cluster (M13). Then look 0.5° north-east for spiral galaxy **NGC 6207**. To see both objects in the same field of view, use a low-power eyepiece.

Through an 8-inch telescope, you'll see an evenly illuminated oval that measures a bit more than twice as long as it is wide. The galaxy orients north-northeast to south-southwest.

Through an 11-inch scope and an eyepiece that gives a magnification of 250x, you'll notice that the north-northeastern edge of this galaxy ends more abruptly than the other one, which appears rounder. A 14-inch instrument at 400x or above will reveal the ultra-thin outer halo that surrounds the bright central region.

Our next target is the **Turtle Nebula** (NGC 6210), and it lies 4° northeast of Kornephoros. Even through a small telescope, you can identify this planetary's magnitude 8.8, light-blue disk easily. Although it is small (14"), NGC 6210's high surface brightness allows you to crank up the magnification but makes spotting the magnitude 12.5 central star a bit iffy. Through the largest amateur

instruments at high magnification, you'll notice the Turtle Nebula is ever-so-slightly oval in an east-west orientation.

Globular cluster **NGC 6229** sits 4.8° east-northeast of magnitude 3.9 Tau (τ) Herculis. At low to medium magnifications, you'll see a nice triangle formed by the cluster and two stars — magnitude 8.0 SAO 46278, only 6' to the west, and magnitude 8.4 SAO 46280, which sits 7' to the southwest.

NGC 6229 lies 90,000 light-years away, so its stars appear faint. The brightest glow at only magnitude 15.5. Through an 8-inch telescope at 200x, you'll see an unresolved glow with an irregular outline. Through a 14-inch scope, you'll pick up about half a dozen stars, and the cluster's face will appear quite mottled.

The unusual designation for planetary **PK 53+24.1** comes from the *Perek-Kohoutek Catalog of Galactic Planetary Nebulae*, first published in 1967. You'll find this magnitude 12.0 object 1.8° east of magnitude 3.4 Mu (μ) Herculis.

The planetary measures only 4.6" across. At magnifications of less than 200x, it will look like a faint star. Another way to confirm its identity is to use at least an 8-inch telescope and an Oxygen-III filter to dim the light of nearby stars. Through the filter, PK 53+24.1 will appear undimmed. Don't confuse it with PK 51+25.1, another magnitude 12 planetary that lies 2.2° to the west-southwest.

Targeting Ophiuchus

Just south of Hercules sits Ophiuchus the Serpent-bearer, the sky's 11th-largest constellation and the highlight of part 2 of our search. Because this region skirts the Milky Way and lies in the general direction of the galactic center, it offers much to observers.

The Milky Way, which contains hundreds of billions of stars, also has areas of great darkness. One is the **Snake Nebula** (B72). Pre-20th-century astronomers believed these starless voids were literal holes in the sky. In 1927, American astronomer Edward Emerson Barnard cataloged 349 dark nebulae. The Snake Nebula was the 74th entry. It carries the designation B72, however, because Barnard added two “extra” numbers to his list before B72: B44a and B67a.

Cold molecular gas and dust, primarily carbon, make up dark nebulae. Such clouds absorb light from nearby stars but do not reradiate it as visible light. Rather,

molecular clouds such as the Snake Nebula give off infrared light.

You'll get your best views of the Snake Nebula through a telescope/eyepiece combination that yields a field of view 0.5° across. Filters don't help because they dim the surrounding stars, reducing the contrast between them and the nebula. To find this object, look 1.4° north-northeast of magnitude 3.3 Theta (θ) Ophiuchi. You'll find the Snake Nebula on the finder chart on page 69.

Spiral galaxy **NGC 5962** lies in northern Serpens Caput, just west of the three stars (Beta [β], Gamma [γ], and Kappa [κ] Serpentis) that form the Serpent's head. This galaxy exhibits "flocculent" spiral structure, meaning its arms appear to be broken into many small pieces in contrast to the "grand design" spirals with well-developed arms. At 150x, you'll notice NGC 5962's broad central concentration. A sharp, bright nucleus some 15" in diameter lies at its center.

The **White-Eyed Pea** (IC 4593) is a planetary nebula you'll find 3.9° west-southwest of magnitude 4.6 Omega (ω) Herculis. Although this object has a common name, you'll need more than just a common telescope to see much detail here. Small instruments show only the magnitude 11.1 central star.

Through a 16-inch scope, the small halo that encases the central star appears, and the halo is blue. Magnifications above 350x show the halo is slightly oval in a northwest to southeast orientation. For the best view through any scope, be sure to place magnitude 7.7 SAO 101998, which lies 11' to the south-southeast, outside your eyepiece's field of view.

You'll need at least a medium-sized telescope to observe spiral galaxy **NGC 6118**. It glows softly at magnitude 11.7 and measures 4.6' by 1.9'. Through a 10-inch scope, you'll see only a faint, uniform haze. A larger telescope at a good observing site reveals a tiny, bright core and weak hints of spiral structure on the galaxy's eastern end. You'll also spot three 14th-magnitude stars embedded in the glow. To find NGC 6118, look 2.6° north-east of magnitude 2.7 Delta (δ) Ophiuchi.

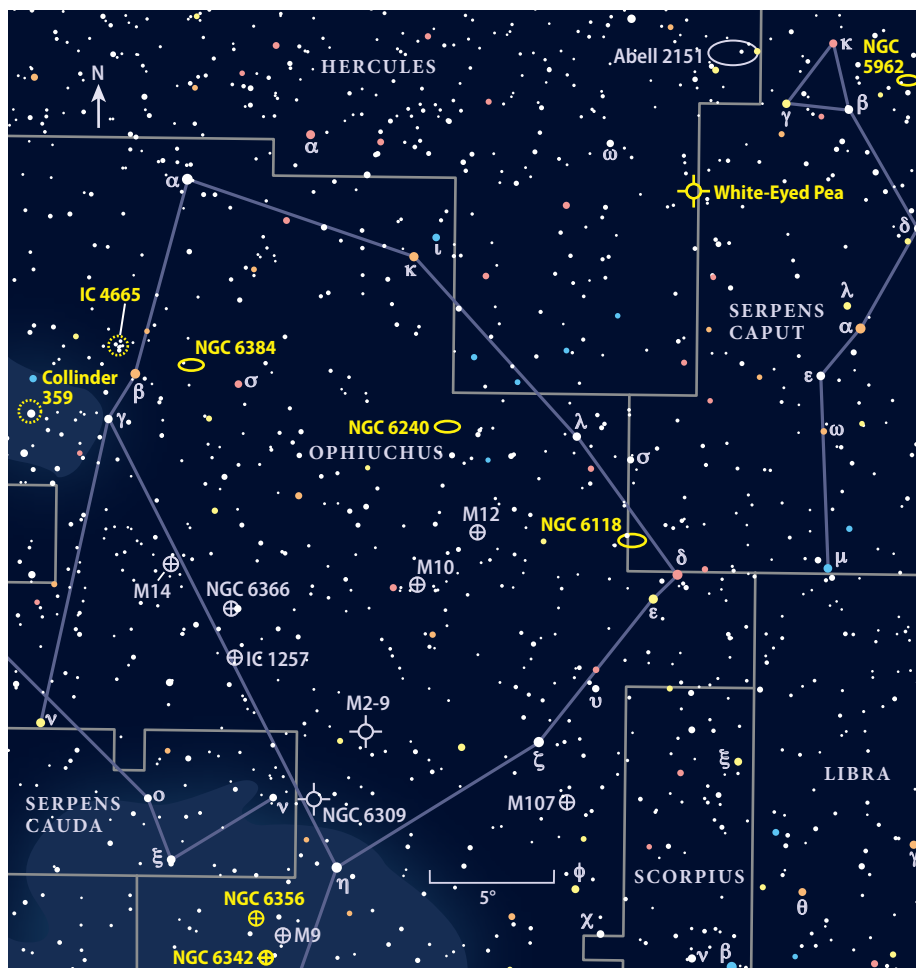
For a different type of galaxy, target **NGC 6240**. This elliptical galaxy appears decidedly non-spherical through large telescopes. It measures 2' by 1' and lies 5.5° east of magnitude 3.8 Marfik (Lambda [λ] Ophiuchi).

With an apparent magnitude of 12.8, you'll need a 14-inch or larger scope to see details in NGC 6240. When you view it, scan its irregular appearance, the result of a violent collision between two previously separate galaxies.

You'll find another nice globular cluster 1.5° north of magnitude 4.4 Xi (ξ) Ophiuchi. **NGC 6342** shines at magnitude 9.5 and measures 4.4' across.

Through an 8-inch telescope, you'll see the moderately bright (but tiny) central region oriented on a northwest-to-southeast line. Even through a 14-inch scope at 300x, most observers resolve no more than half a dozen stars that lie at the limit of visibility.

NGC 6356 is another of Ophiuchus' many globulars. This object sits 3.8° east-southeast of magnitude 2.4 Eta (η) Ophiuchi. Although you'll spot this globular easily through a finder scope, its 50,000-



Ophiuchus the Serpent-bearer is the 11th-largest constellation. It contains many open and globular clusters, planetary nebulae, and even a few galaxies. *Astronomy:* Richard Talcott and Roen Kelly



▲ **The Snake Nebula (B72)** stretches for 4' in Ophiuchus. Stars will form from this molecular cloud. Jason Ware

light-year distance makes it a challenge to resolve individual stars. Through an 8-inch telescope at 200x, you'll see an irregular border surrounding the broad central region. When I last viewed NGC 6356, I saw no halo region even through a 14-inch scope.

It's OK if you've never observed (or even heard of) **IC 4665**. Although it's a relatively bright open cluster some observers call the Little Beehive, it won't appear that bright to you. That's because its light spreads out over a diameter of 70' — 5.5 times the area of a Full Moon.

IC 4665 lies 1.3° north-northeast of magnitude 2.8 Cebalrai (Beta Ophiuchi). To observe the cluster, use a low-power eyepiece that will give you at least a 1° field of view. You'll see several dozen 7th- to 9th-magnitude stars and another 20 stars around magnitude 10 set against a rich background haze of fainter points.

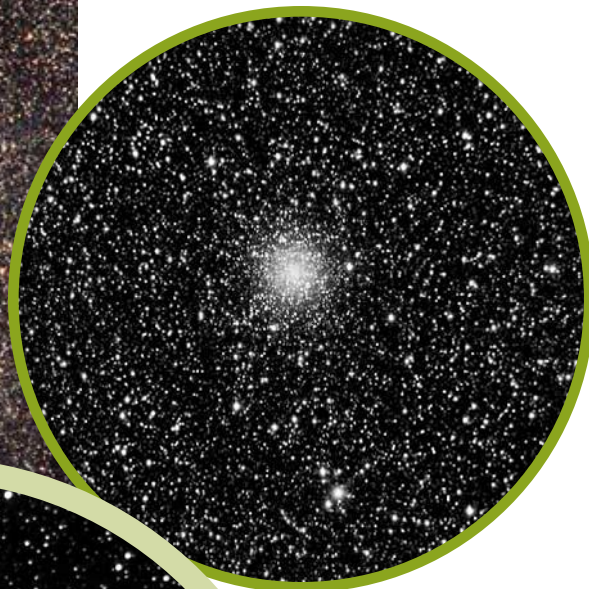
My best view of IC 4665 came through an 8-inch f/4.5 Newtonian reflector

Michael E. Bakich is an Astronomy senior editor.

equipped with a binoviewer. Using eyepieces that gave a magnification of around 45x, the cluster took on a layered 3-D appearance.

Astronomy Contributing Editor Stephen James O'Meara calls this object the Black Swallowtail butterfly. He sees a black body and white-spotted wings represented by the stars in this cluster.

I've often thought that **NGC 6384** is an odd duck. It's a reasonably bright (magnitude 10.4) spiral galaxy in Ophiuchus. You'll find this object 3.7° northwest of Cebalrai. Through an 8-inch telescope at 150x, this object appears nearly rectangular. It measures 6.2' by 4.1'. The galaxy has a broad, bright central region that orients from the north-northeast to the



▲ **Globular cluster** NGC 6356 lies in Ophiuchus and is relatively bright at magnitude 8.2, but its stars are difficult to resolve.

Martin C. Germano



◀ **Spiral galaxy** NGC 6384 stands out because Ophiuchus doesn't contain many bright galaxies.

Martin C. Germano

south-southwest. Larger-aperture scopes and higher magnifications reveal a faint halo that hugs the galaxy's core. Done with NGC 6384, and

ready for even more of an observing challenge? Then try to locate magnitude 14.0 NGC 6378, a small spiral galaxy, 0.9° to the south-southwest.

You may think I've gone bonkers by putting a 3rd-magnitude binocular object that spans 4° on this list, but hear me out. **Collinder 359**, also known as Melotte 186, centers on the star 67 Ophiuchi. The cluster includes the bright stars 66, 68, and 70 Ophiuchi, about a dozen 7th- and 8th-magnitude members, and some 200 stars brighter than 12th magnitude.

When you've taken a quick look, head for a dark site, pull out a 12-inch or larger scope, crank the power past 200x, and observe "through" the cluster. Within 1.5° of 67 Oph lie half a dozen faint galaxies. The brightest is magnitude 15.0 PGC 61292, which lies 1° south-southeast.

Milky Way treasures

Our final map centers on Scorpius, which lies south of Ophiuchus. You could spend the whole summer observing objects in this one star group. If you feel compelled to observe the four Messier objects (open clusters M6 and M7, and globular clusters M4 and M80), do so quickly, and let's get down to business.

The bright planetary nebula **NGC 6072** sits in Scorpius, but the easiest way to find it is to look 1.4° east-northeast of magnitude 4.2 Theta (θ) Lupi. Through a 6-inch telescope, this magnitude 11.7 object appears as a featureless, 40"-wide circular disk. A 12-inch scope, an eyepiece that magnifies about 250x, and a nebula filter reveal a moderately dark rift splitting NGC 6072 into northern and southern halves. Note also how the edge appears irregularly bright.

To find our next object, look 4.8° west-southwest of magnitude 3.0 Mu (μ) Scorpii. A 4-inch telescope easily reveals globular cluster **NGC 6139** against a rich

starry background. It shines at magnitude 9.1 and measures 8.2' across. But simply spotting this object and seeing detail in it are two different things. You'll need at least a 14-inch scope and a magnification above 300x to resolve even a few of its stars. What you'll see through smaller instruments is a dense core surrounded by an unevenly lit halo.

Another of the many planetary nebulae in Scorpius, **NGC 6153** lies 4.5° west-southwest of Mu Scorpii. Through an 8-inch or larger telescope, you'll need high magnification (above 200x) to reveal this magnitude 10.9 object as anything other than a bloated "star" roughly 25" across. An Oxygen-III filter helps the identification because it dims the surrounding stars but not the nebula. Look for unevenness in NGC 6153's edge and an ever-so-slightly darker central region.

Our next target is a combination of an open cluster, **NGC 6193**, and an emission nebula,

NGC 6188. Most observers can spot the magnitude 5.2 cluster with their naked eyes from a dark site. You'll find it 2.7° east-southeast of magnitude 4.8 Epsilon (ε) Normae. But even a 4-inch scope under a dark sky reveals the faint haze that weaves through open cluster NGC 6193. Use a magnification of 150x.

▼ **Globular cluster NGC 6397** is one of the brightest objects on our list, but its southerly location makes it an under-observed object.

Michael Sidonio



Emission nebula NGC 6188 only looks this detailed in images, but a medium-sized telescope will still provide a great view. Open cluster NGC 6193, which includes the bright stars below and left of center, shines at magnitude 5.2 and runs throughout much of the nebula's area. Gerald Rhemann and Michael Jäger

Through 10-inch and larger scopes, you'll see a lot more detail in the nebula, which stretches some 20' by 12'. Note the dark region that separates the eastern section from the western one. Pay close attention to the nebula's edge, which appears irregularly bright and dark.

The bright but relatively unknown open cluster **NGC 6250** lies in Ara 3.6° southwest of magnitude 3.3 Eta (η) Scorpii. A 4-inch telescope will show about a dozen stars brighter than magnitude 12. An 8-inch scope shows the same number. Through an instrument with a 12-inch aperture, however, dozens of background stars appear, giving NGC 6250 a multi-layered appearance.

The five brightest stars in the grouping form a rough, wide "M" shape 7' across. The two luminaries are magnitude 7.6 SAO 227508 and magnitude 7.9 SAO 227500, both of which sit at the eastern edge.

The magnitude 8.2 globular cluster **NGC 6293** lies 1.2° west of the magnitude 4.3 double star 36 Ophiuchi. Don't confuse it with the brighter M19, which lies 1.7° to the west. Through a 10-inch telescope at 200x, you'll notice this globular's bright, condensed core and a much fainter irregular halo. Crank the magnification to 350x, and NGC 6293 subdivides into clumps of unresolved stars. Several foreground stars lie within the field of view. The brightest is magnitude 8.4 SAO 185111, which sits 12' northeast of the cluster's center.

Globular cluster **NGC 6316** sits 1.6° south of 36 Ophiuchi. Through a 10-inch telescope, this magnitude 8.1 object has a bright, broad core with a faint halo. The globular spans only 5.4', so you won't resolve many cluster members. You will, however, see a magnitude 11.0 foreground star 1' southeast of the core.

You'll need at least a 16-inch scope and a dark sky to spot the **Cotton Candy Nebula** (CRL 6815). Not only does it glow faintly at magnitude 14.5, but it's also small, only 16" long. Astronomers note that this object falls into a rare class called protoplanetary nebulae, objects that soon will form young planetary nebulae. Only about 350 are known.

You won't see detail in this object, so look for its elongated nature. It's nearly



Scorpius the Scorpion isn't a huge constellation, but because it lies in the Milky Way's band, it contains a multitude of deep-sky wonders. *Astronomy: Richard Talcott and Roen Kelly*

twice as long as it is wide. Use magnifications in excess of 350x.

NGC 6380 is a challenging globular cluster you'll find 1.5° west of magnitude 2.4 Kappa (κ) Scorpii. We view this magnitude 11.1 object through 35,000 light-years of interstellar material, so just spotting it is prize enough. Through a 12-inch scope, NGC 6380 appears as a faint, broadly concentrated haze 3.9' across.

NGC 6380 also carries the designation Ton 1, derived from Tonantzintla Observatory, which lies near Puebla, Mexico. From there, Turkish astronomer Paris Pismis (1911–1999) discovered this globular cluster and another even fainter one, Ton 2, in 1959. To see magnitude 12.2 Ton 2, look 25' east of NGC 6380.

Our next fine target lies 2.9° northeast of magnitude 2.9 Beta (β) Arae, or 0.9° north-northeast of magnitude 5.3 Pi (π) Arae. As the sky's fourth-brightest globular cluster (its magnitude, 5.3, ties for that honor with NGC 6752 in Pavo), **NGC**

6397 certainly would have earned a Messier designation if it were in the northern sky. It covers 74 percent of the area of a Full Moon.

If you observe from a location that puts this cluster more than 10° up in the sky, you'll find it easily visible with your naked eyes as a fuzzy star. Through an 8-inch telescope at 200x, some 50 stars lie concentrated toward the brighter middle.

Through a 14-inch scope at high power, the view is remarkable. Stars of all brightnesses form patterns. The entire cluster resolves, and some observers have likened its appearance to an open cluster.

This list includes only a small fraction of the faint, strange, or under-observed objects lurking in the summer sky. Target them through your telescope, and you'll find why they bring many observers more joy than even Messier's catalog. ☿

 Find locations and more for all these objects at www.Astronomy.com/toc.

Binocular stargazing

10 top summer binocular treats

You won't need a large telescope to spot these celestial wonders.

by Phil Harrington



Summertime, stargazing, and binoculars. In my mind, the three are inseparable. Is there anything better than sitting back with binoculars and scanning the summer Milky Way as it flows overhead? To start you off on your journey across the summer binocular universe, I've compiled a top 10 list of my favorite seasonal targets.

The Hero's cluster

In May, we begin high in the eastern sky with the **Hercules Cluster** (M13). Aim a third of the way from brilliant Vega (Alpha [α] Lyrae) to Arcturus (Alpha Boötis), and you'll see a faint smudge of light along the western side of Hercules' dim Keystone asterism. Hard to believe, but what looks like a tiny ball of celestial cotton is actually a massive collection of more than 100,000 stars, which astronomers classify as a globular star cluster (because of its globe shape). M13 lies 25,000 light-years away.



The Butterfly Cluster

Bernhard Hubl

Star clouds in Scorpius

The **Butterfly Cluster** (M6) and **Ptolemy's Cluster** (M7) are two open star clusters in Scorpius. They sit near the stinger stars Shaula and Lesath (Lambda [λ] and Upsilon [υ] Scorpii) at the end of the Scorpion's curved body. Place those stars at the bottom edge of your binoculars' field of view, and you will

see two distinct bundles of stars to their upper left.

M6, the smaller and more northerly of the pair, looks roughly rectangular. Some observers imagine that its stars form a butterfly's outline, with two wings outstretched. The butterfly appears to be flying toward the southeast.

M7, mentioned by Greek philosopher Ptolemy around A.D. 130 and thus called Ptolemy's Cluster, is larger and brighter than M6. Even through the smallest binoculars, several of the cluster's stars show subtle hints of yellow and blue. The brightest is a golden sun lying near the group's center.

Phil Harrington is an Astronomy contributing editor.

The Archer's lagoon

Shifting eastward, we arrive at the constellation Sagittarius the Archer, with its distinctive Teapot asterism. By scanning the Milky Way streaming northward from the Teapot's spout, you'll pass several bright clumps of starlight. The largest, which lies about a binocular field of view north of the spout, is a huge emission nebula called the **Lagoon Nebula** (M8).

The nebula appears lopsided, with the western side more bloated than the eastern half. If you have dark skies and a steady hand, you might spot the dark lagoon that divides the nebula in half. The magnitude 5.9 star 9 Sagittarii sits west of the lane.

A celestial swan

Farther north along the Milky Way in Sagittarius we come to the **Swan Nebula** (M17), another emission nebula. Look for it about 1½ fields of view north of the Teapot's lid and just south of a yellowish 5th-magnitude star. With a magnification of 10x or more, look for a straight bar of light along the cloud's northern edge. Can you also see a faint hook of nebulosity curving off the bar's western end? It's this hook-and-bar shape that gave rise to the Swan Nebula nickname.



M22

Bernhard Hubl

A southern cotton ball

While many observers cite this list's first object — M13 — as their favorite summer globular cluster, I prefer **M22** in Sagittarius because of its aesthetics. M13 is isolated in Hercules, but M22 is right in the thick of the Milky Way. Look for its circular glow about half a binocular field northeast of Kaus Borealis (Lambda Sagittarii) at the Teapot's top. Binoculars easily show a fuzzy halo surrounding a brighter core.



R. Jay Gabany

The Wild Duck Cluster



Conrad Pope

The North America Nebula

Like birds in flight

The **Wild Duck Cluster** (M11) sits in Scutum, but the easiest way to find it is to look 4° west-southwest of the magnitude 3.4 star Lambda Aquilae, one of the tail stars of Aquila the Eagle. M11 is one of the sky's densest open clusters. More than 600 of M11's stars shine brighter than 15th magnitude, but only a single 8th-magnitude rebel is bright enough to show through binoculars. The rest blend into a small, bright mist of starlight that looks more like a globular than an open cluster.

Hang around these stars

The **Coathanger** (Collinder 399), which lies in Vulpecula the Fox, is one of my all-time favorite binocular objects. It's easy to find if you look about two fields northwest of Altair, Aquila's brightest star. Even a casual scan will immediately reveal the asterism's unique shape. Ten stars glow brighter than 7th magnitude. Six in a straight line form its crossbar, and another four to the south curve to create the hook. Powers of 7x to 10x give the best view of the Coathanger dangling in a star-filled closet.

A continent in the sky

Our last object needs a dark sky, but once you spot it, it's sure to become a favorite. Simply aim your binoculars toward Deneb in Cygnus, and look roughly half a field of view (3°) to its east. Can you see a slightly brighter, hook-shaped patch of Milky Way? That's the **North America Nebula** (NGC 7000). The easiest part to see is the East Coast as it stretches from Long Island to Florida and then around to the Gulf of Mexico.

Enjoy each of these targets and then branch out on your own to discover more of what this season has to offer. Summer is made for binocular stargazing. And remember that, as always, two eyes are better than one. ☾



Mark Hanson

The Dumbbell Nebula

The sky's dumbbell

Normally, planetary nebulae don't show up well through binoculars because they appear so small. The **Dumbbell Nebula** (M27) is an exception. It looks distinctly rectangular through 10x binoculars, while higher magnifications hint at its characteristic hourglass profile. Look for it half a binocular field north of magnitude 3.5 Gamma (γ) Sagittae, the brightest star in Sagitta the Arrow.



Explore more images of these summer binocular objects online at www.Astronomy.com/toc.

Sun-spotting

Fun observing the Sun

Double your observing time by targeting our daytime star. by Michael E. Bakich

Many observers consider the Sun the ultimate celestial villain because it robs them of valuable telescope time. But look on the bright side (pun intended). The Sun is easy to find and offers plenty of detail. Plus, you'll get great views through any size telescope, and capturing solar images takes little time.

Be safe, not sorry

The first item of business for any solar observer is eye safety. Make sure you use an approved solar filter from a reputable manufacturer. This isn't something that you can make yourself out of shiny candy wrappers. High-quality solar filters remove infrared and ultraviolet radiation and allow only a small fraction of the Sun's visible light through.

Also, never use a solar filter that attaches to an eyepiece. A solar filter must cover the entire front end of your telescope. That's where the light enters. If you need convincing, see Glenn Chaple's "Observing Basics" column in *Astronomy's* January 2010 issue.

Pick a viewing method

Actually, there is one way you can view the Sun without a filter: Use your telescope for solar projection. Observers who favor this method trace the Sun's disk and any visible sunspots. This technique provides better positional accuracy over sketching freehand.

Manufacturers classify solar filters by the wavelengths of light they transmit. The most popular are visible-light filters. As the name implies, these filters trans-

mit visible wavelengths (at a much reduced level). Visible-light solar filters allow you to see sunspots, granulation (surface mottling), occasional faculae (small bright areas), and limb darkening.

The next most-popular filter allows only light with a wavelength of 656.28 nanometers to pass through. That wavelength marks an emission of red light that occurs when an electron in a hydrogen atom drops from the third to the second energy level. Physicists labeled this emission Hydrogen-alpha ($H\alpha$), so you'll need an $H\alpha$ filter to see it.

$H\alpha$ observing allows amateur astronomers to view normally hidden solar features like the chromosphere (the layer beneath the visible surface) and prominences. Through these filters, solar flares appear as white regions on the Sun's disk, and often such features change in mere minutes. The only reason $H\alpha$ observing is less popular than visible-light observing is cost. $H\alpha$ filters typically cost 10 to 50 times as much as visual ones.

View when conditions are best

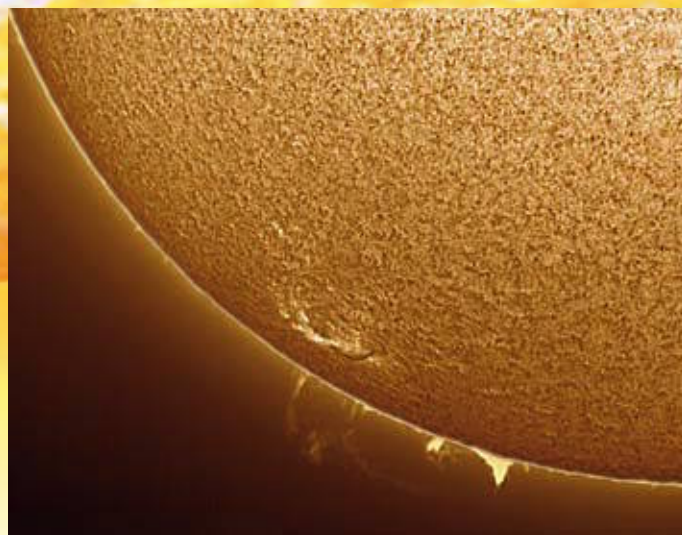
In most locations, morning is the best time to observe the Sun. The daytime atmosphere is coolest then, so the movement of heated air produces less distortion that your telescope will reveal. This isn't always the case, so be sure to test this general rule at your observing site.

When I lived in El Paso, Texas, afternoon proved to be the best time to view the Sun. My house sat just west of the Franklin Mountains. In the morning, as the mountains heated up, the air above them became unstable. My most steady views, therefore, came after noon when the Sun stood in the western sky.

Michael E. Bakich is an Astronomy senior editor.



The green flash (arrow) is a short-lived optical phenomenon that may occur at the first moment of sunrise or the last instant of sunset. A green flash takes place when atmospheric refraction bends light of other wavelengths (colors) away from view. Most observers report green flashes over ocean horizons, but one may occur over any distant, unobstructed horizon. Jim Grant (www.scenicsandiegophotos.com)



These images, taken only 5 minutes apart, show the same part of the Sun's disk September 22, 2009. The photographer took the left exposure through a visible-light filter. For the right image, he used a Hydrogen-alpha ($H\alpha$) filter. Note the additional features visible through the $H\alpha$ filter. David Tyler

Draw!

Atmospheric stability allows you to observe the Sun's rich details. You can do so visually, but there's also a way you can capture solar details without being an astroimager. Try sketching the Sun.

You don't have to be an artist to produce a good image. Be happy with your work. You will improve. Sketching will make you a better observer. You must memorize small areas of detail before transferring what you're seeing to paper. The more objects you sketch, the more honing in on small details will become part of your normal observing routine.

As a practical matter, don't make the circle that represents the Sun too large. The first few times I sketched the Sun, I used circles that barely fit on a large sheet of paper. Each one took forever to make! After a few of these marathon sessions, I settled on a circle approximately 3 inches (7.6 centimeters) in diameter.

The best way to start sketching the Sun is to use pencils with dark, soft lead on white paper — and don't hesitate to use your eraser. To capture the “not-so-dark” areas around sunspots, some observers lightly smudge what they've drawn with a finger.

For this technique, coarse-grade sketching paper seems to work best, as does lots and lots of practice. It's OK to do some light touch-up work to fill in

shaded areas after your sketching session as long as you don't add details you didn't see through the scope.

Catch a solar eclipse

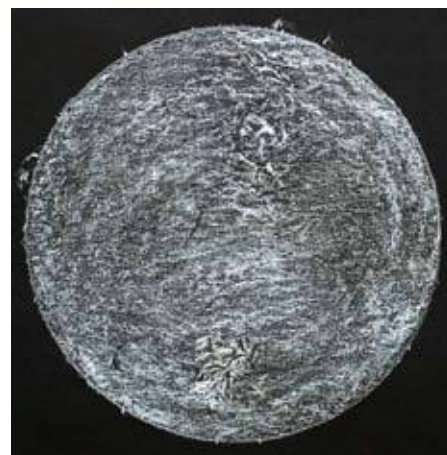
The same safety precautions to observe the Sun are in effect during solar eclipses. The only exception occurs during totality. First contact signals the eclipse's start, but the real action begins at second contact as the Moon fully covers the Sun.

In 1836, the English astronomer Francis Baily noticed a string of irregularly spaced, brightly lit points at the edge of the Moon just before totality. Now known as Baily's beads, you can spot this phenomenon several seconds before and after totality. The beads are actually the last few rays of sunlight shining through valleys on the Moon's limb.

Immediately before totality, just before the last vestige of sunlight vanishes, the corona appears. Observers long ago dubbed the combination of one brilliant point of light and the round corona the “diamond ring.” View it once, and you'll never forget it. At this point, remove any filters from your scope. The view is safe until the next diamond ring appears.

After the first diamond ring vanishes, you may be able to glimpse the reddish chromosphere. This is a difficult observation because it lasts for only about a second, but it's the only time you can spot the chromosphere without an $H\alpha$ filter.

Now and throughout totality, you may see large solar prominences with your naked eyes. Observers who have seen



This sketch of the Sun shows features visible to the observer through a Hydrogen-alpha filter. The label “AR 1017” refers to an active region, an area with a strong magnetic field that usually contains sunspots. Erika Rix

multiple total solar eclipses tend to remember each by the size of the largest prominences and by the corona's overall shape. Take advantage of this view. The wispy outer atmosphere of the Sun is now in view. Even experienced eclipse-goers have no idea how the corona will appear prior to totality. It's always a surprise. For a guide to the next total solar eclipse, see “Totality crosses Easter Island” in the March 2010 issue of *Astronomy*.

Sun-watching offers something for everyone. You can follow sunspots in visible light, watch solar flares erupt in $H\alpha$, or chase eclipses halfway around the world. However you choose to observe it, the Sun will provide an ever-changing vista of high-quality views. ☼



To learn more about individual solar features, see “How to observe the Sun” at www.Astronomy.com/toc.



Vixen's new refractor outperforms its specs

The AX103S offers fine craftsmanship and superb optics in a small package.

by Glenn Chaple



Being a budget-minded individual, I usually work with lower-end telescopes. For this review, however, I decided it was high time to try out a luxury instrument. My road-test vehicle has a name with a sports car ring — the AX103S. This 4-inch (103 millimeter) apochromatic refractor from Vixen Ltd. is to the backyard astronomer what a Porsche or Ferrari would be to an automobile fancier.

First impressions and features

The AX103S has the sleek, shiny look of a high-performance sports car — a gleaming pearl tube embossed with red lettering. Its maker, Japan's Vixen Ltd., has produced high-quality telescopes for more than 60 years.

The AX103S uses a different lens than achromatic refractors that were prevalent decades ago. Unlike an achromat, whose objective consists of two optical elements, the Vixen AX103S has a three-element objective.

The central lens boasts extra-low dispersion (ED) glass designed to reduce chromatic aberration (colors focusing at different points) and improve image contrast. A fourth optical component — a field corrector lens positioned toward the rear of the tube — ensures sharp images across the field of view.

Features I appreciated include the dual-speed rack-and-pinion focuser and the retractable dew shield. When retracted, it reduces the tube's overall length from 30 to 27 inches (76 to 69 centimeters).

Under the stars

First light with the AX103S was a star test using brilliant Vega (Alpha [α] Lyrae). A high-power view revealed a crisp, tight image of the star with no chromatic aberration. Images inside and outside focus indicated flawless optics.

The four components of the Double Double (Epsilon [ϵ] Lyrae) stood out sharply, even through a 2.5mm eyepiece (330x). This magnification is well above the theoretical upper limit for a 4-inch scope. I was amazed at the ability of the AX103S's f/8 optics to handle such high magnification.

The Moon looked impressive through the AX103S, its features etched sharply across the field of view. With high anticipation, I turned to Jupiter, rising above the treetops. Although atmospheric turbulence at that altitude muddled the image, no color fringes surrounded the planet's disk. Clouds dashed my hopes of viewing this planet when it stood higher in the sky — a weather pattern that plagued me for much of the time I had allotted to the AX103S review. At times, I felt like someone trying to test-drive a convertible during a rainstorm!

I was able to explore a few deep-sky objects. A view of globular clusters M4 and the Hercules Cluster (M13) revealed sparkling stellar spheres. The Ring Nebula (M57) was definitely annular, contradicting my one-time belief that its "ring-ness" could be seen only through



The optical system of the AX103S employs a three-element objective lens and adds a fourth element — a field corrector lens — within the tube. Vixen multicoats all optical surfaces.

Contact information

Vixen Ltd.

1023 Calle Cordillera
Unit C

San Clemente, California 92673

[t] 949.429.6363

[w] www.vixenoptics.com



Vixen Ltd's AX103S is a high-quality 4-inch apochromatic telescope with an f/8 focal ratio. Its superb optics allow high-magnification views.

All equipment photos:
Astronomy: William Zuback

larger telescopes. A comparative view through my trusty 4.5-inch reflector showed just a ghostly oval. Now I know why many amateur astronomers gravitate to apochromatic refractors.

As for light-gathering ability, the AX103S can go deep. An accompanying pamphlet gives the instrument's limiting magnitude as 11.8. Not so! Checking out stars of known brightness around the variable star SS Cygni, I saw a magnitude 12.3 star without using averted vision.

Because I reviewed only the optical tube assembly, I needed to add a mount. I easily affixed the AX103S to a budget mount I own. The setup worked fine for low-power views, but it wasn't always steady enough for the high magnifications the AX103S is capable of reaching. Should you purchase this optical tube assembly, you'll want to place it on a premium mount.

Vixen sells complete AX103S packages that serious observers will appreciate. The packages include one of the company's high-quality mounts, a 7x50 finder scope, a flip-mirror diagonal, and a Vixen eyepiece.

A testament to the razor-sharp optics of the AX103S came not in the course of nighttime observing, but during a daylight test by my friend Bill Pothier. Bill aimed the telescope at a steeple atop his backyard barn. Using a 4mm eyepiece (206x), he clearly saw the

threads on an exposed bolt. He was admiring the sharp detail when he noticed movement — an ant. From a distance of 70 yards (64 meters), Bill could tell that the ant was missing an antenna.

In a word, superb

So how do I feel after test-driving a "Porsche"? Spoiled! There's still a place for my budget scopes, and they serve me well. But on those nights when the seeing and transparency are optimal, I'll wish I were behind the wheel of an AX103S.

Should you count yourself among the ranks of veteran skygazers who feel it's time to cruise around the universe in style, give serious consideration to purchasing Vixen's AX103S. It's a telescope that, if properly cared for, will last a lifetime. ☺

Product specifications

Vixen AX103S

Type: Apochromatic refractor

Aperture: 4 inches (103 millimeters)

Focal length: 825mm

Focal ratio: f/8

Weight (tube assembly): 10 pounds
(4.6 kilograms)

Cost: \$2,999



The dual-speed 2" focuser Vixen includes with the AX103S allows both coarse and fine adjustments.

Glenn Chaple is an Astronomy contributing editor and columnist.



Evening Stars

by David H. Levy

A special star party in upstate New York

Gazing at the wonders of the dark sky with like-minded friends never loses its allure.

One of the advantages of writing a monthly column in *Astronomy* magazine is that I can promote a particular event I think has value to our readers, especially those just beginning their astronomical voyages. I've often felt that a star party in the Stellafane tradition, but limited to a smaller, more intimate group of people, would be perfect.

This summer, from August 6 to August 13, our Sharing the Sky Foundation, led by my wife Wendee and me, will hold its seventh annual Adirondack Astronomy Retreat. For advanced observers, the goal is to help rediscover why we became interested in the night sky in the first place. For beginners, the idea is to gather under some of the darkest skies in the northeastern United States, look up, and feel the magic of the night.

Nature grants us a special event this year: a chance to view the Perseid meteor shower under dark, moonless conditions. It doesn't happen often; either the Moon brightens the sky and washes out all but the brightest meteors or the urban light pollution bedevils us and prevents any possible faint-meteor sightings. This summer will provide us with a fabulous sky for observing the Perseid meteors, assuming

the sky remains clear, of course. In that happy instance, the rates of falling meteors should increase through the night.

Our campsite there has a lot of personal memories linked to it as well. In the summer of 1964, it served as the site for my first summer specifically devoted to



This scenic campsite, in the midst of the Adirondack Mountains in upstate New York, becomes even more picturesque at night, offering one of the darkest spots in the northeastern United States. It has long been home to some of the author's most fond skygazing memories. *David H. Levy*

observing. The next year it led to my decision to begin a lifelong quest searching for comets, writing books, and, most recently, completing a Ph.D. dissertation. I saw my first major aurora there in 1966. And over the past 6 summers, the site has served as the home of our retreat.

Each year has provided at least one good night; we were particularly lucky in 2008 with six! During clear skies, the site offers one of the darkest spots in the northeastern United States. It is dark enough to spot the Andromeda Galaxy (M31) easily with the naked eye, but on good nights I have even seen the faint glow of the Triangulum Galaxy (M33).

One night, around 2 A.M., a stray meteor appeared high in the sky, then exploded as it careened toward the forested southern horizon. The meteor must have been at least magnitude -8 . It was an utter thrill to see that event — proof positive that the sky serves as an arena

where dramatic action can occur, with events to enthrall the eye and enrich the mind.

The best part of this star party is the friends we make — often the same group returns year after year, clouds or not. People like astrophotographers Greg Taylor and Bob Masterson display photographs they take of deep-sky objects during the retreat. Another of our regular attendees, Dr. Martin Rice, always offers good sugges-

tions for observing simply and efficiently. Although our regulars are advanced observers, every one of them, without exception, is happy to answer questions from newcomers and guide them into the avocation we love.

The campsite has a certain magic that comes out each clear evening. The only urban glows we see are from the east and north, while the rest of the sky, especially the south toward the heart of Adirondack Park, remains totally dark.

I hope to see some more of *Astronomy's* readers this summer. For more information, write info@sharingthesky.org. Relax, recharge, and soar. ☾



Browse the "Evening Stars" archive at www.Astronomy.com/Levy.

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Mike Barber

Vice president and co-founder of SBIG

Mike Barber, a co-founder of the Santa Barbara Instrument Group and a lawyer for about 20 years, can obviously feel at home in two separate worlds. Sometimes, he even does it literally. “My wife, Nui, and I currently have a home in Santa Barbara and a home in Thailand, where she was born,” he says. “We go back and forth about once each year.”

Barber was born in Berkeley, California, and, despite extensive travel through Asia, he’s lived in the state all his life. And most of that time he’s loved astronomy, thanks to a friend of his grandfather. “One night [the friend] brought over a telescope he made in his garage,” Barber says. “I remember seeing the homemade mirror and looking through the eyepiece at Orion and Saturn.”

Barber’s father also played a part in cultivating this interest. “My dad used to take us to [San Francisco’s] Morrison Planetarium,” Barber says. “It was a real thrill for me to deliver a talk on CCD imaging in that same planetarium many years later!”



Mike Barber, vice president and co-founder of SBIG, thinks technology like the CCD camera will be essential tools for the future amateur astronomer. courtesy Mike Barber; background: HST/NASA/ESA

What’s something cool about Santa Barbara Instrument Group (SBIG) that nobody knows?

We literally started our business in a garage. In the 1980s, before SBIG, we were a small group of amateur astronomers doing research in our backyards searching for optical counterparts to gamma-ray bursts. We called ourselves the Santa Barbara Astronomy Group.

or so of any desired coordinates. But it did much better than this, and they kept getting better up to the ST-4, which would guide reliably to better than one arc-second. That’s good enough to guide an hourlong astrophoto.

So we formed SBIG and started selling this autoguider to other astrophotographers. Interestingly, after 20 years we just released a new stand-alone autoguider, a successor to the original

enough to observe with even modest scopes, and I never get tired of seeing Saturn and Jupiter as they change their appearance over the course of a night, a week, or a season.

Can you share anything about new products?

We have broken tradition slightly and made a single sensor camera that we feel will be very popular. We made it a single sensor version because of cost. Bringing out a multi-megapixel camera with such a low price will make CCD imaging more affordable to those who may be

considering stepping up from a DSLR to a dedicated astronomy camera. Our new camera is based on Kodak’s KAF-8300 CCD, an 8.3-megapixel chip available in both monochrome and color versions. We’ve put it in a small, lightweight package with a new smaller optional filter wheel.

Where, in your opinion, is the hobby headed?

Clearly computers and electronics are reshaping the way we live, and this includes our hobby. Lenses and mirrors are already incredibly good, but one can add to this with adaptive optics devices, for example. To see even more, you need to use something in place of your eye. This is where the CCD camera comes in.

Amateurs with a modern CCD camera can take images equal to the best professional observatories just 10 to 20 years ago. Amateur observers make important discoveries all the time nowadays. So I see the upper end of the hobby becoming more scientific, with advanced amateurs placing their scopes at prime dark sites and operating them over the Internet from thousands of miles away. At the other end, I see the beginner and casual observer able to go out and get a more modest, but still complete, system. ☛

“We have broken tradition slightly and made a single sensor camera that we feel will be very popular.”

We all had day jobs, so we needed something to help keep our telescopes tracking accurately if we left them alone. One of us, Alan Holmes, designed a “Star Tracker” using a CCD to perform this task, calling it the ST-1. We needed it to keep the scope pointing to within an arcminute

ST-4. We call the new model the SG-4 in honor of the original.

Do you personally enjoy observing?

Yes, of course. Because I live in a relatively light-polluted area, I enjoy looking at the Moon and planets. They’re always bright



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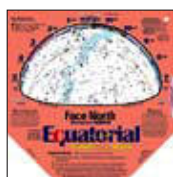
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Ken Press' Equatorial Guide to the Stars is a planisphere designed for use near the equator, but it has a useful range from latitudes 30° north to 30° south. The planisphere is made of heavy paper stock coated to be water repellent. The instructions are in English and Spanish.

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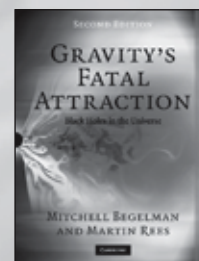
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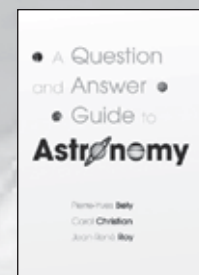
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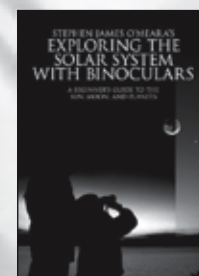


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INDEX of ADVERTISERS

Adirondack Video Astronomy	83	Observatory Inc., The	83
ADM	83	Obsession Telescopes	84
Adorama	19, 27	Oceanside Photo & Telescope	27, 81
Astronomy.com	77	Optic Wave Laboratories	82
Astronomy Binders	17	Optical Mechanics, Inc.	83
Astronomy magazine	81	Optics Planet	27
Arctic Odysseys	84	Orion Telescopes & Binoculars	3
Ash Manufacturing	84	Owl Services	82
Astro Haven	82	Pro-Com Electronics	82
Astro-Physics	83	Quantum Scientific Imaging, Inc.	15
Astrodon	84	Rainbow Symphony	82
Astronomics	9	Santa Barbara Instrument Group	27
Astronomy Technologies	82	Science Kit & Boreal Lab	27
Aurora Astro Products, LLC	84	Scope Buggy	84
B&H Photo	27	Scope City	27, 83
Ball Aerospace Technology	5	ScopeStuff	82
Beta Electronics	82	SCS Astro	84
Bob's Knobs	83	Sirius Observatories	82
Cambridge University Press	79	Sky Shed	82
Celestron	7	Smartastronomy.com	84
Denkmeier Optical	84	StarGPS	83
Glatter, Howard	84	Starmaster Portable Telescope	83
Hands on Optics	27	Stellarvue	27, 84
Interstellar Studios	5	Teaching Company, The	4
Into the Wind- The Kite Source	83	Technical Innovations	17
ISTAR Optical	82	Tele Vue Optics, Inc.	89
Jewelry Designs for Men	82	TravelQuest International	82
Jim's Mobile, Inc.	19	Vixen Optics	2
Kahn Scope Centre	83	Wood-Wonders	84
Knightware	84	Woodland Hills Cameras & Telescopes	17, 27
Lightbuckets.com	19	www.bigbinoculars.com	82
Majestic Optical Coatings	83	The Advertiser Index is provided as a service to Astronomy magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.	
Meade Instruments Corporation	90		
Northeast Astronomy Forum	77		

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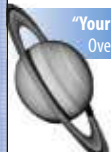
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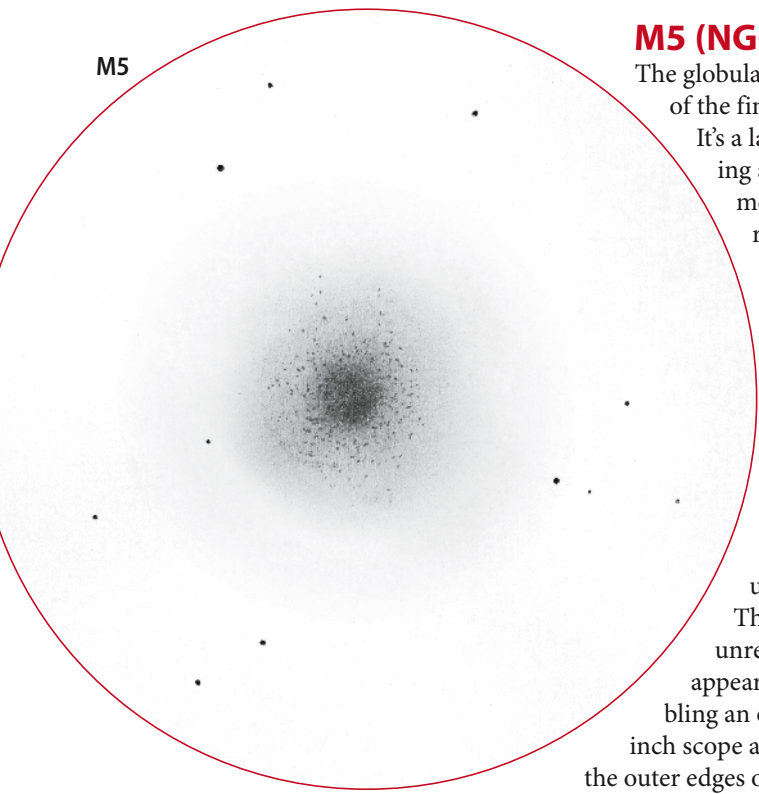
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Deep-sky Showcase

Astronomy's editor sketches two of his favorite objects. **by David J. Eicher**

A tale of two clusters

M5



M5 sketched by David J. Eicher using an 8-inch f/10 SCT at 50x.

M5 (NGC 5904)

The globular star cluster M5 is one of the finest clusters in the sky. It's a large globe of stars shining at magnitude 5.7, and it measures 23' across, corresponding to a physical diameter of 125 light-years. As globular star clusters go, M5 is a neighbor — it lies high above the galactic plane some 25,000 light-years away.

Because it's so bright, M5 is visible to the naked eye as a "star" under dark skies.

Through binoculars, this unresolved patch of light appears as a fuzzy disk resembling an out-of-focus star. A 6-inch scope at high power resolves the outer edges of M5, revealing its stellar nature and transforming it into a fascinating object. Large backyard scopes

M5



Sally and Curt Kling/Adam Block/
NOAO/AURA/NSF

Designations: M5, NGC 5904
Position: 15h19m, 2°05' (2000.0)
Constellation: Serpens Caput
Magnitude: 5.7
Size: 23'
Distance: 25,000 light-years

under dark skies resolve stars fully across M5's face, providing unforgettable views.

A large scope reveals scads of stars around the cluster's face, resolving M5 into an impressive glow. Use a high-power eyepiece to examine chains and arcs of stars on the group's perimeter. Look closely to see if you can detect differences in star colors. Who says all globular clusters look alike?

NGC 2419



Doug Matthews and Charles Betts/
Adam Block/NOAO/AURA/NSF

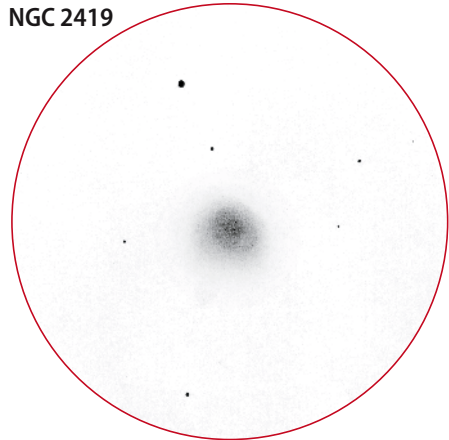
Designation: NGC 2419
Position: 7h38m, 38°53' (2000.0)
Constellation: Lynx
Magnitude: 10.4
Size: 4.1'
Distance: 300,000 light-years

NGC 2419

One of the best deep-sky treats found in Lynx is NGC 2419, a small globular cluster located in the same field as a 7th-magnitude star. NGC 2419 isn't a tremendous sight as globulars go. The key word with NGC 2419 is distance — it lies about 300,000 light-years away, making it one of the Milky Way's most distant globulars. Because of NGC 2419's great distance, the eminent astronomer Harlow Shapley nicknamed the cluster the "Intergalactic Tramp," believing it may have broken the gravitational chains of the galaxy.

Observationally, NGC 2419 appears as a circular smudge in an interesting, sparsely star field. A large scope shows it as an oval glow with little resolution — only the largest telescopes amateur astronomers have access to can begin to resolve

NGC 2419



NGC 2419 sketched by David J. Eicher using a 17.5-inch f/4.5 reflector at 70x.

David J. Eicher is the editor of *Astronomy*. He has observed and sketched deep-sky objects for 34 years.

the cluster into component stars. A 30-inch scope under a dark sky provides a tantalizing view of the cluster's brightest stars broken into resolution. ☼



The California Nebula (7.2-inch Takahashi E-180 Newtonian reflector at f/2.8, SBIG ST-10XME CCD camera, Sulfur-II/Hydrogen-alpha/Oxygen-III image with exposures of 7.5, 4.5, and 8 hours, respectively) • Daniel B. Phillips, Oceanside, California

California, here we come

The California Nebula (NGC 1499) is the only deep-sky object named for one of America's states. It lies in southern Perseus 1° northeast of magnitude 4.0 Menkib (Xi [ξ] Persei). The nebula's luminous portion spans 100 light-years. However, this entire region contains vast hydrogen clouds from which many bright, massive stars have formed. Astronomers labeled the family of young stars here the Perseus OB2 association. This image features mapped color: Red shows exposures taken through a Sulfur-II filter, green substitutes for Hydrogen-alpha, and blue represents Oxygen-III emission.



Spiral galaxy NGC 660 lies in Pisces. The photographers dedicated this image to the late astronomer Daniel Marquardt. (9-inch TMB refractor at f/9, SBIG ST-11000 CCD camera, LRGB image with exposures of 26.3, 7.3, 7.9, and 9.2 hours, respectively) • Dietmar Hager and Immo Gerber, Tao Observatory, Provence, France



Sharpless 2-98 in the southern part of Cygnus blends into the background under visual observation but shows ring structure in a CCD image like this one. (8-inch Maksutov-Newtonian telescope at f/4, SBIG ST-10XME CCD camera, H α RGB image with 14 hours and 30 minutes total exposure time) • [Dean Salman, Tucson, Arizona](#)



◀ **The Fornax Dwarf** belongs to the Local Group and lies approximately 500,000 light-years away. Although it glows at 8th magnitude, it measures 17' by 12', so its surface brightness is low. (4-inch Takahashi FSQ-106ED refractor at f/5, SBIG STL-11000M CCD camera, LRGB image with exposures of 4, 2, 1.5, and 2 hours, respectively) • [Jason Jennings, Melbourne, Australia](#)



Sharpless 2-185 is a faint emission nebula that lies near magnitude 2.2 Cih (Gamma [γ] Cassiopeiae). (6.4-inch Astro-Physics StarFire refractor at f/7.7, Apogee Alta U16M CCD camera, SII/H α /OIII image with exposures of 100, 70, and 70 minutes, respectively) • [Phillip L. Jones, Frisco, Texas](#)



The area between emission nebula NGC 1333 and open cluster IC 348 in Perseus glows with red emission and blue reflection nebulosity. Dark dust also spreads through this region, blocking out the light from more distant stars and nebulae. (4-inch Takahashi FSQ-106EDX refractor at f/3.64, SBIG STL-11000M CCD camera, LRGB image with exposures of 200, 50, 40, and 60 minutes, respectively) • [John A. Davis, Dallas](#)



A Geminid fireball blazes through the constellation Orion over the Mojave Desert. The photographer took 1,522 images during a 12-hour period. The photos captured 48 Geminids. (Canon 5Di digital SLR, Canon L

24mm f/1.4 lens at f/2.2, 25-second exposures, the photographer took the one above at 3:29:45 A.M. PST, December 14, 2009, in the Mojave Desert 40 miles east of Victorville, California) • [Wally Pacholka/AstroPics.com/TWAN](http://WallyPacholka/AstroPics.com/TWAN)

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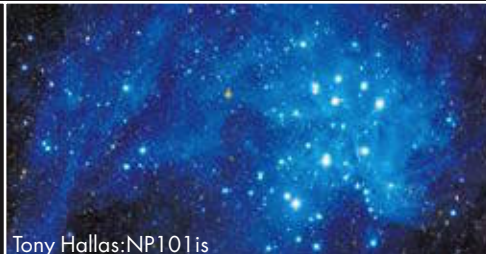
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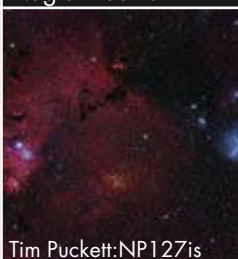
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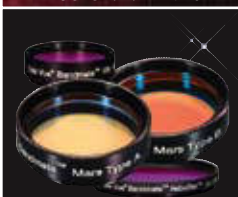
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